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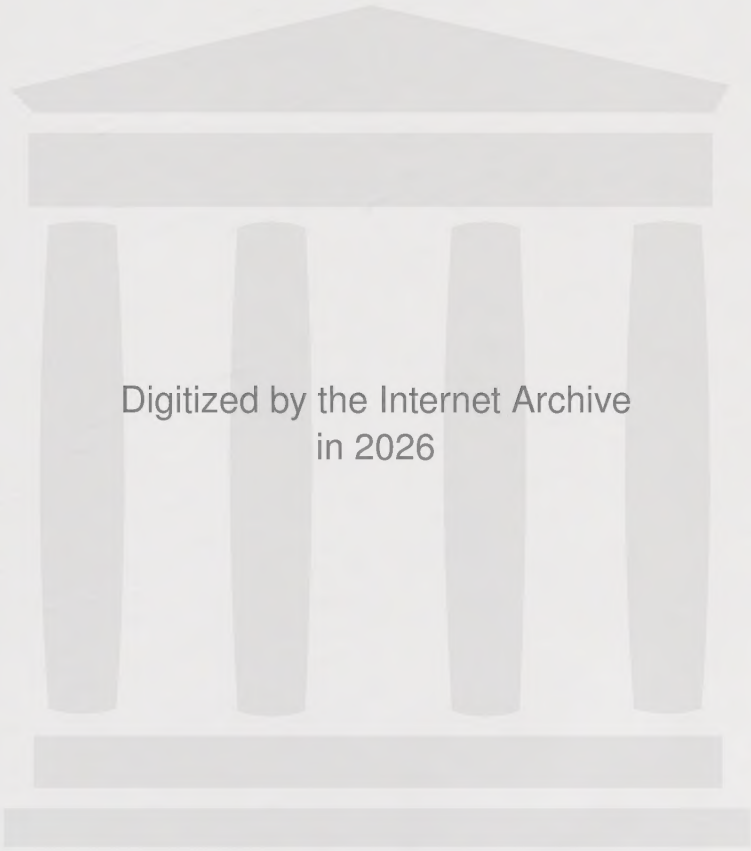
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REPORT

OF THE

GEOLOGICAL SURVEY

OF OHIO.

VOLUME VI.

ECONOMIC GEOLOGY.

PUBLISHED BY AUTHORITY OF THE LEGISLATURE OF OHIO,
UNDER THE SUPERVISION OF THE STATE GEOLOGIST.

COLUMBUS:
THE WESTBOTE CO., STATE PRINTERS.
1888.

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OFFICERS OF THE SURVEY.

EDWARD ORTON, ... STATE GEOLOGIST.

N. W. LORD, ... CHEMIST.

ASSISTANTS.

F. W. MINSHALL.
F. H. NEWELL.
EMERSON MCMILLIN.
S. W. ROBINSON.

C. NEWTON BROWN.
ELLIS LOVEJOY.
WILLIS J. ROOT.
M. R. CAMPBELL, Draughtsman.

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PREFACE.

Volume V, Geology of Ohio, was published in 1884. Although it contained more than 1100 pages, it not only failed to include a number of the subjects that certainly deserve a place in a work treating of the Economic Geology of Ohio, but it also failed to provide room for several chapters that had been already prepared. Among the latter was a single chapter on the oil and gas production of Ohio as developed at that time.

In view of these facts, Governor Hoadly recommended to the Legislature in January, 1885, that the chapters already prepared for publication, and other chapters to be prepared on subjects pertaining to the economic geology of the state, should be published under the title, Geology of Ohio, Volume VI. Action was taken in accordance with this recommendation, and an appropriation of $4,500 was made for carrying forward the necessary work. It was also ordered that a small edition of the chapter on Petroleum and Natural Gas should be published in advance of the volume. October 1, 1885, was fixed as the date of this publication.

This year proved to be the beginning of by far the most remarkable movement ever experienced in the geology of Ohio. Surprising developments, in the way of oil and gas production, from sources to which neither geologist nor oil producer had ever looked with any expectation of large results, were going forward in the state and it required all the resources of the Survey to keep pace with these developments. Instead of a single chapter on oil and gas, as originally contemplated, the necessity for a half dozen chapters was made apparent, or in other words, the chapter was expanding to the proportions of a volume.

When October came, the material in hand had so far outrun the limits of the chapter on which the action requiring its publication in advance had been based, that it was counted best to withhold it until January, and to leave the disposition of the new report to the incoming Legislature. The chapters were promptly offered to the Legislature and the recommendation was made by the State Geologist that they should be issued at once, as a volume of the Survey Reports exclusively de-

voted to petroleum and gas. If the recommendation had been adopted, this volume would have been issued in 1886.

The Legislature finally decided in May, 1886, to continue the work of the Survey until February, 1887, in the enlargement of the volume, appropriating $3,000 for this purpose, and ordering the State Geologist to publish meanwhile, an abstract of his investigations on petroleum and gas. This abstract was at once prepared and was published in July, 1886, under the title, "Preliminary Report on Petroleum and Inflammable Gas in Ohio." By it the first authentic information in regard to the new gas-fields and oil-fields of Northwestern Ohio was made public. The interest in the subject was wide-spread and the publication of this little volume was therefore timely. Its facts and conclusions helped to supply a somewhat more intelligent basis for the exploration that was going forward on all sides.

On February 1, 1887, the date fixed by the Legislature, the chapters for Volume VI were presented for publication, and on March 11, the volume was ordered to be published, the necessary appropriations being voted for this purpose. The action of the Legislature in ordering the publication was practically unanimous, only two opposing votes being cast against the bill.

Immediate steps were taken to carry out this action, but to the surprise and regret of all concerned, it was found, after the adjournment of the Legislature, that by clerical oversight, the bill had neither been enrolled nor signed. On account of its imperfect condition, the Auditor of State refused to count it law and to place upon his books the appropriation which the Legislature had voted. The question was brought before the Attorney-General, who confirmed the decision of the Auditor of State.

In the endeavor to avoid, if in any way possible, the delay in publication that would thus be occasioned, and with the approval of Governor Foraker, who counted it well that the question involved should be definitely settled, the State Geologist brought suit in the Supreme Court of Ohio, by Hon. George K. Nash, in the name of the firm who had contracted to supply the paper for publication, to compel the Auditor of State to place upon his books the appropriation which the Legislature had, as all agreed, designed to make. The Court pronounced an elaborate opinion through Justice Spear, sustaining the position of the Auditor of State and Attorney-General.

The contractors for the state printing and also the firm to which the contract for supplying the paper for the volume had been let, agreed, however, to go on with their respective parts of the work, relying upon the next Legislature to make good their outlays. The State Geologist supplied copy, and thus the volume was substantially ready for publication January 1, 1888. Governor Foraker called attention

in his annual message to the facts already stated, and recommended a re-enactment of the legislation of last winter that had been found defective. This action was promptly taken and the long-delayed volume, considerable portions of which have been twice rewritten, at length sees the light.

The bulk of the volume is devoted to the subjects of oil and gas, as is proper, in view of the recent astonishing developments in Ohio. Fortunately for the author, there was, in the latter part of 1887, a little lull in the storm of exploration that has raged in the state for the last four years. Of this he has gladly availed himself in getting his record into print. The statements of the volume are thus a little nearer to the present conditions of the field than they could have been if published at any other time within the period above named, but it does not require a very careful reading to find in the text the traces of frequent revision. More than this, the conclusions which larger experience has given will be found side by side, to some extent, with the earlier generalizations from a smaller and less important line of facts. In spite of all the unpaid labor that has been expended in this revision and extension of the report, there are still some sections of the field to which scant justice has been done.

If the volume could be written as a whole with present knowledge, it is certain that the emphasis with which some of the facts are stated and the inferences drawn from them would vary in many points from the inferences and emphasis which now obtain. Such results are to be expected, however, as long as continued study is given to such subjects as these.

Something has been learned in regard to the geology of petroleum and inflammable gas from the study of the new fields in Ohio, but a great deal more remains to be learned. There are few, questions pertaining to the subject to which full and final answers can now be given, but the facts relating to Trenton limestone oil and gas that are here presented, are sure to be recognized by all students in this department of geological science as of great significance and importance. The new Ohio field is destined to become classical ground in such study.

In the legislation ordering the present volume, it was required that the coal fields of the state which were not treated of in Volume V, should be here described. This work was undertaken, and excellent chapters will be found on the Pittsburgh coal in Eastern Ohio and in the Pomeroy field, by Messrs. Brown and Lovejoy respectively. Reliable maps of the coal areas accompany these chapters. One important section of the first named field was omitted in this review, from want of time in 1886, and from want of funds in 1887. Reference is made to Harrison county. It is a matter of sincere regret that it has been found necessary to

do such injustice to its fine body of coal lands as to leave them without mention or mapping in the present volume.

Another omission to fully comply with the law providing for publication must be acknowledged. A chapter was to be prepared on the composition, strength and durability of Ohio building stones. In its preparation, a good deal of time has been spent, and the facts accumulated would have been found to possess both scientific interest and practical value, but unfortunately, the data obtained have been mislaid or lost, and time has not been found to repeat the observations and tests. A large part of the work had been done on the Berea Grit.

In recording the great number of facts that it has been attempted to incorporate in this volume, it can scarcely be otherwise than that errors of statement will occur. It can be truly said in extenuation of such inaccuracies, that pains have not been spared in gathering the facts. It must be remembered that the sources of such information are varied and unequal in value, and that exactness is not always attainable.

To the companies that have been formed in so many of the towns of Ohio to explore the underlying rocks for gas and oil or to utilize the same when found, to the contractors and drillers who have done the practical work of exploration and exploitation, and to a great body of intelligent observers beside, the Geological Survey is greatly indebted. Information of great value has been freely given by all, and few attempts to mislead or deceive have been detected.

A half dozen persons have been so painstaking in supplying the accumulating facts from their several fields, that it would be wrong to leave them without special acknowledgments, although such mention may seem almost invidious in the presence of the great number whose services are scarcely less.

Reference is made to Hon. L. C. Sawyer, of St. Mary's; Hon. George C. Phelps, of Bowling Green; Capt. George P. Waldorf, of Lima; Milton Taylor, of Toledo, and David A. Wolff, of Bryan.

The chemical work of the volume constitutes one of its most interesting and important features. In no other state of the Union has the chemical composition of the s ·ed out as extensively as in Ohio.

Special acknowledgments are also due to the officers of various railroad lines who have contributed greatly to the success of the field-work that underlies this volume, by giving free transportation for all or portions of the time to the officers of the Survey. The appropriations by the Legislature have been small, and it would have been impossible to do what has been done in the accumulation of facts, without the assistance afforded in the way here indicated.

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GEOLOGY OF OHIO.

CHAPTER I.

THE GEOLOGY OF OHIO, CONSIDERED IN ITS RELATIONS TO PETROLEUM AND NATURAL GAS.

By Edward Orton.

The subjects to be discussed in this and the four succeeding chapters are of large and increasing interest to the people of the state at the present time. The recently acquired importance of natural gas in western Pennsylvania, and in northwestern Ohio, in particular, has led to earnest inquiry and in many cases to expensive search for this admirable fuel in various districts of Ohio, and this search is certain to be extended until every county in the state not only, but every city and enterprising village as well has made its test.

Inasmuch as the utilization of both petroleum and gas on the large scale is of quite recent date, the geological facts pertaining to their distribution and accumulation, to say nothing of their modes of origin, are still but imperfectly known, and consequently the geological theories concerning these subjects are still incomplete and inadequate. These facts are, however, rapidly accumulating, and the generalizations based upon them are consequently becoming more trustworthy as guides in the work of practical development.

It is to the well-driller's art that we owe the acquisition of these new sources of power. The drilling of deep wells has long been carried on in various portions of the world; in some countries it has been practiced for many hundred years. The mode of drilling now in use in this country, however, owes nothing whatever to this varied foreign experience, but the art is, in all respects, a native one. The steps of its evolution are all on record and none of them dates beyond the early years of the present century.

American practice in this field is immensely in advance of all other, and in fact this business has become with us almost a distinct branch of mechanical engineering. Years of experience are required to gain a full knowledge of it, and those who attain such knowledge command the consideration and pay of other mechanical experts.

Rock-boring in this country, or at least the drilling that has led directly to our present practice, was begun in 1806, in the Kanawha Valley, by the Ruffner brothers, who were searching for salt water strong enough and abundant enough to warrant the establishment of salt furnaces at the points where the drilling was done. Their search was successful, and well-drilling has gone on uninterruptedly from that date to the present time in this and in adjoining regions, and it is here that all of the most distinctive and characteristic features of the American system of deep drilling have originated. To the Kanawha Valley we owe the "casing" of wells, whereby surface waters are excluded, the "seed-bag," or packer, by means of which the contents of deep-lying strata are separated from the contents of all overlying strata at pleasure, the "jars" or "slips" which make one of the most indispensable elements of the driller's outfit. An admirable account of the successive steps in the development of well-drilling tools and machinery was furnished by Dr. John P. Hale, of Charleston, West Virginia, for Professor M. P. Maury's centennial account of the resources of West Virginia. This account is copied in Professor Peckham's report on Petroleum, which appears in volume X of the United States Census Reports, Washington, D. C., 1884.

Another account of almost equal value is to be found in Dr. S. P. Hildreth's "Observations on the Bituminous Coal Deposits of the Valley of the Ohio and the accompanying Rock Strata," etc., which appeared in the American Journal of Science in 1836.

It was this Kanawha Valley system of rock-drilling, improved and expanded by fifty years of experience, mainly in the salt wells of the Ohio Valley, that the oil-well-driller found at his command when the petroleum excitement of 1858 broke out in western Pennsylvania. Under the stimulus of this extraordinary demand, the efficiency of the drilling tools has been greatly increased and the character of the driller's outfit greatly improved since this date, but only one important addition has been made to the system itself, by all of the extended experience of the oil regions. The addition referred to consists in the use of torpedoes, lowered into the wells to the depth of the oil or gas-producing stratum and there exploded. By this means the production of deep wells is often greatly increased. In many districts a well is not considered finished until it is torpedoed or "shot," to use the driller's term.

These new facilities for underground exploration have been very widely used within the last few years, and from them we have learned a great number of geological facts—some of them of extreme interest and importance. Among other things, we have learned that petroleum and inflammable gas are almost universally distributed throughout the stratified rocks of this part of the world. The drill very seldom descends for even a few hundred feet through any portion of our various rock-formations without disclosing their presence. To find them "in paying quantity" is, of course, the rare exception, but small amounts of one or both are rarely if ever missed, whether the drill descends through sandstone, shale or limestone of Carboniferous, Sub-carboniferous, Devonian, Upper Silurian or Lower Silurian age, or even through heavy beds of bowlder clay.

It thus appears that a review of the several sources of petroleum and gas in the Ohio geological scale, for example, would necessitate a review of this scale itself. In fact, no description of the occurrence of these substances in our strata can be made fully intelligible unless the geological order is held firmly and distinctly in mind. A brief review of the scale of the state will accordingly be furnished at this point.

A. The Geological Scale of Ohio.

The geological scale of Ohio comprises strata of Lower Silurian, Upper Silurian, Devonian, Sub-carboniferous and Carboniferous age, and also a series of glacial deposits. The principal divisions are shown in the following table. The thickness that is assigned to each of the elements is not necessarily the average thickness of the various exposures. In some cases, the general measure is given; in others, it is counted better to indicate the thickness of some of the more characteristic exposures. In the text, the limits of each formation will be more definitely given:

18.	Glacial drift		0 to 550 feet.		
17.	Upper Barren Coal Measures		500 "	Carboniferous.	
16.	Upper Productive Coal Measures		200 "		
15.	Lower Barren Coal Measures		500 "		
14.	Lower Productive Coal Measures		250 "		
13.	Conglomerate Group		250 "		
12.	Sub-carboniferous limestone, Maxville, Newtonville, etc		25 "	Sub-carboniferous.	
			500 "		
11.	Waverly Group	11e Logan Group, 0 350 11d Cuyahoga Shale, 150–450 11c Berea Shale, 20– 50 11b Berea Grit, 3 to 160 11a Bedford Shale, 50–150	500′ to 800′	500 "	

10.	Ohio Shale { 10c Cleveland Shale; 10b Erie Shale.....; 10a Huron Shale..... }	250 to 3,000 ft.....	300 "	Devonian.
9.	Hamilton Shale (Olentangy Shale?)		25 "	
8.	Devonian Limestone, Upper Helderberg or Corniferous, including West Jefferson sandstone		75 "	
7.	Lower Helderberg limestone or Waterlime, including Sylvania sandstone, 50 to 600 ft.....		500 "	Upper Silurian.
6.	Niagara Group { 6d Hillsboro' sandstone .....; 6c Guelph or Cedarville limestone, 50–200.....; 6b Niagara limestone .....; 6a Niagara Shale, including Dayton limestone, 5 to 100..... }		30 " 150 " 50 " 100 "	
5.	Clinton Group, in outcrop, 20 to 75 ft.; under cover, 75 to 150.....		50 " 75 "	
4.	Medina Shale, in outcrop, 25′; under cover, 50 to 150...			
3.	Hudson River Group, 300′ to 750′		750 "	Lower Silurian.
2.	Utica Shale, not seen in outcrop, but 300 ft. thick under cover in Northern Ohio.....		300 "	
1.	Trenton limestone, seen only in Pt. Pleasant quarries...		50 "	

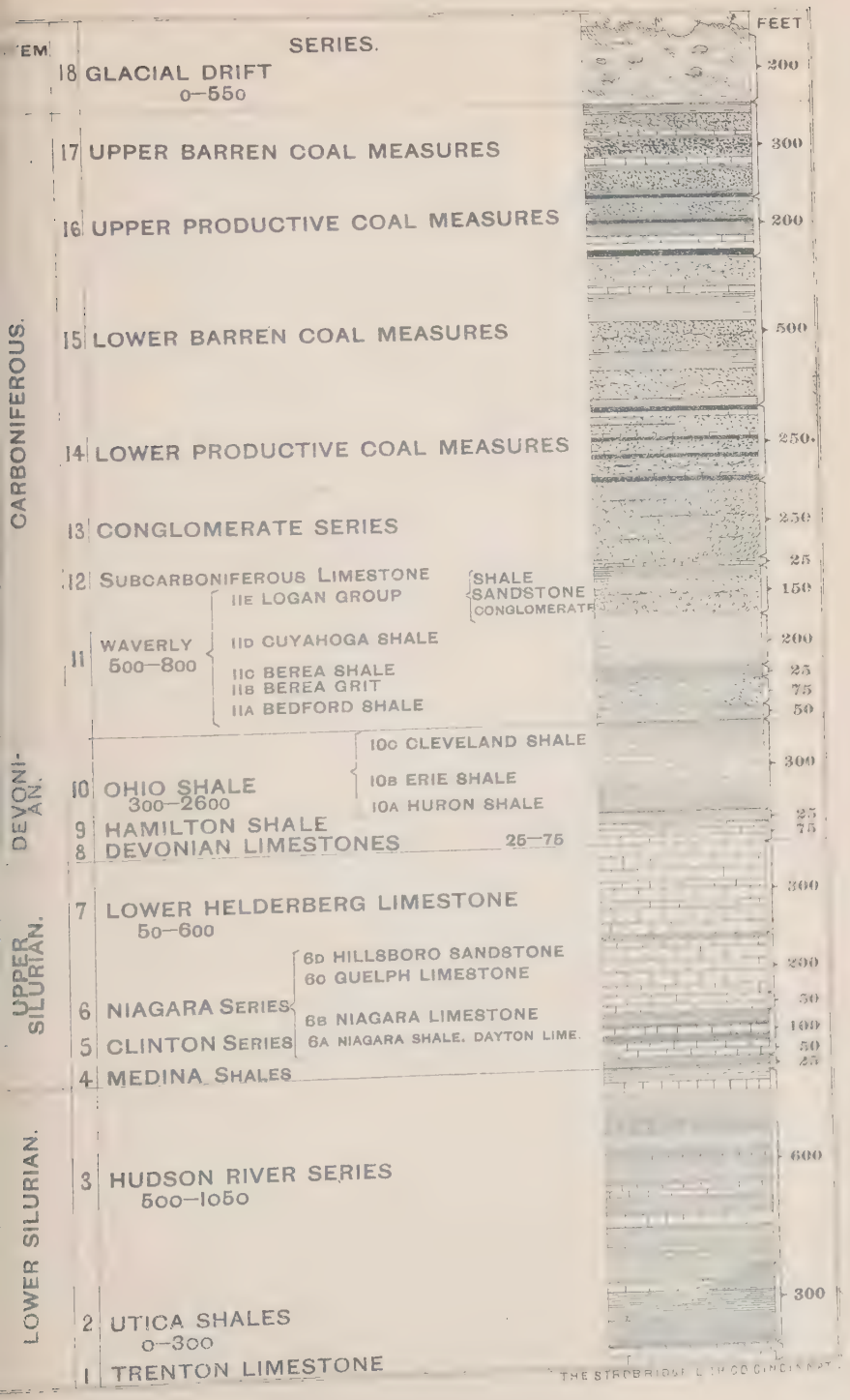
The geological order above described is further represented in the accompanying diagram, figure I. A brief review of each of these divisions will next be made.

1. The Trenton Limestone.

The Trenton limestone is one of the most important of the older formations of the continent. It is the first wide-spread limestone of the general scale. It extends from New England to the Rocky Mountains, and from the islands north of Hudson's Bay to the southern extremity of the Alleghany Mountains in Alabama and Tennessee. Throughout this vast region it is found exposed in innumerable outcrops. It gives rise as it decays to limestone soils which are sometimes of remarkable fertility, as for example, those of the famous Blue Grass region of central Kentucky, which are derived from it. It is worked for building stone in hundreds of quarries, and it is also burned into lime and broken into road metal on a large scale throughout the regions where it occurs. But wide-spread as are its exposures in outcrop, it has a still wider extension under cover. It is known to make the floor of entire states in which it does not reach the surface at a single point.

It takes its name from a picturesque and well-known locality in Trenton township, Oneida county, New York. The West Canada Creek makes a rapid descent in this township from the Adirondack uplands to the Mohawk Valley, falling 300 feet in two miles by a series of cascades. These cascades have long been known as Trenton Falls, and the limestone which forms them was appropriately named by the New York geologists, the Trenton limestone. The formation, as seen at the original

VERTICAL SECTION OF THE ROCKS OF OHIO.



locality, is found to be a dark-blue, almost black limestone, lying in quite massive and even beds, which are often separated by layers of black shale. Both limestone and shale contain excellently preserved fossils of Lower Silurian age. By means of these fossils, and also by its stratigraphical order, the limestone is followed with perfect distinctness from Trenton Falls to every point of the compass. It is changed to some extent, in color and composition as it is traced in different directions, but there is seldom a question possible as to its identity. The Trenton limestone forms several of the largest islands in whole or in part in the northern portion of Lake Huron, as the Manitoulin Islands and Drummond's Island. It dips from this region to the southward, but it is found rising again in outcrop in the valley of the Kentucky river. Its presence underneath the entire states of Ohio and Michigan, and especially under western Ohio, has always been inferred, since the geology of these states was first worked out. But the claim now and here to be made, viz., that the Trenton limestone rises to the surface within the limits of Ohio, appears for the first time on this page in the publications of the Geological Survey. It was shown in Volume I, Geology of Ohio, page 370, that the lowest rocks of the state that appear at the surface are to be found in the quarries of Point Pleasant, which are located in Clermont county, about twenty miles above Cincinnati. These lowest rocks have received the name by which they are distinguished from this locality. A thickness of fifty feet was claimed for the Point Pleasant beds, and they were referred on what seemed good ground to the Cincinnati group. At a later day the claim was made by Mr. S. A. Miller, in a paper read before the Natural History Society, that the Point Pleasant rocks were in reality the Trenton limestone rocks of Kentucky, rising to day at this sole point in Ohio. The claim was afterwards repeated by Mr. W. M. Linney, of the Kentucky Geological Survey. But no occasion for revising the geological column of Ohio, since its first publication, has arisen until now.

It may seem surprising that the discovery of unquestioned Trenton limestone in Ohio should be made in the northern portion of the state, where the stratum lies buried 1,000 to 2,000 feet below the surface, and that by following this stratum southward, by means of the numerous well-records lately made available, it should at last be found rising to day in the quarries of Point Pleasant, confirming the identifications of the rock as quoted above, but this surprise will disappear when the new section is understood. It is the presence of the Utica shale to the northward, in its most characteristic form, that enables us positively to identify the Trenton limestone there, and it is the disappearance of the same shale cover in the Ohio Valley that has left us hitherto uncertain

as to the upper boundaries of the Trenton limestone in this region. The facts bearing on this identification will be found on later pages of this report, but for the present it is sufficient to state that there is good reason to accept the identification first made by S. A. Miller, Esq., of the Point Pleasant rocks, as Trenton limestone. This famous stratum thus becomes the foundation of the Ohio geological column, although it has but a single outcrop in the state.

The character of the rock found at Point Pleasant is briefly described in the chapter of Volume I, Geology of Ohio, already quoted. The limestone is a light or grayish blue limestone, quite crystalline in structure, massive in its bedding, and fossiliferous. The solid courses are interrupted to some extent by thinner beds of shale. It breaks under the drill into thin flakes rather than into cubical grains. The analysis of a single sample of the Point Pleasant limestone is as follows: (No. 1). The analysis of the same stratum taken from 300 feet below the surface at Cincinnati is appended, (No. 2), as is also the analysis of the stratum as found at Hamilton at the depth of 550 feet. (No. 3).

	1	2	3
Carbonate of lime	79.30	78.70	84.70
Carbonate of magnesia	0.91	1.93	1.50
Silicious matter	12.00	12.95	12.00
Alumina and iron	7.00	5.04	1.50

The limestone is seen to be in this analysis impure and of a character that by its decay would leave a large residue to the forming soil. In some parts of northwestern Ohio, the Trenton limestone is a magnesian limestone of a high degree of purity. Its composition, as seen in the gas rock of Findlay and the oil rock of Lima, is herewith appended:

Trenton limestone at Findlay, 1,096 feet below surface, 1.
" " Lima, 1,247 " " 2.
" " Bowling Green, 1,092 feet below surface, 3.

	1	2	3
Carbonate of lime	53.50	52.66	51.78
Carbonate of magnesia	43.05	37.53	36.80
Alumina and iron	1.25	4.15	4.89
Silicious residue	1.70		

The Galena division of the Trenton limestone of Illinois and Wisconsin is a dolomite, like the oil rock of Northwestern Ohio. In Kentucky, the Trenton limestone has a moderate percentage of magnesia in its composition. In New York it is higher in carbonate of lime, and contains comparatively little magnesia. This whole subject of the chemical composition of the Trenton limestone will be more fully discussed on a later page.

While the Trenton limestone in its uppermost beds is thus seen to make the lowest rocks that rise to the surface in Ohio, it is still true that the drill is revealing to us the composition of the underlying series for many hundred feet below it. The thickness of the Trenton limestone proper can only be judged by a study of the formation as it appears in outcrop to the southward. Mr. W. M. Linney, of the Kentucky Geological Survey, in a paper on the rocks of central Kentucky published in 1882, gives the thickness of the Trenton limestone in Kentucky as 175 feet. The Bird's-eye limestone which directly underlies it, he finds to be 130 feet in thickness, and the Chazy next below 300 feet in thickness; the entire series being thus about 600 feet in thickness. It is altogether probable that these three limestones constitute the solid mass which the drill has so often penetrated in Ohio within the last year or two to a depth five or six hundred feet. The formations which the geologist separates when they rise to the surface are counted by the driller as a single limestone, for which he needs no other name than Trenton. The several divisions, however, are found to vary considerably in grain, in color, and in chemical composition. Below this great limestone a sandstone more or less calcareous is reported in most of our deep wells. This is on the horizon of the Saint Peter's sandstone of the northwest and very likely deserves to be called by this name. It is forty to sixty feet thick, as generally found, and is charged with the rank salt and sulphur water which is known as Blue Lick water, though water of the same grade is sometimes found in or between the limestones above named. Still deeper, impure magnesian limestones again occur that may probably be referred to the Calciferous period. The facts pertaining to these portions of our series will be brought out in connection with the accounts of these deep wells to be subsequently given.

2. The Utica Shale.

The immediate cover of the Trenton limestone from which it derives its name is a well-known stratum of black shale 300 feet in thickness, which, from its abundant outcrops in the vicinity of Utica, received from the New York geologists the name of Utica shale.

This stratum has proved to be very persistent and wide-spread. It is sparingly fossiliferous, but several of the forms that it contains are characteristic, that is, they have thus far been found in no other stratum. The first of the deep wells that was drilled in 1884 in Findlay revealed to our surprise, at a depth of 800 feet, a stratum of black shale containing the most characteristic fossil of the Utica shale, viz., *Leptobolus insignis*, Hall, and it was thus positively identified with the last-named formation. This bed of shale has the normal thickness of the Utica shale in New York, viz., 300 feet, and with the other elements involved, it extended and continued the New York series into northern Ohio in a most unexpected, and at the same time, in a most satisfactory way.

The Utica shale, thus discovered and defined, is a constant element in the deep wells of north-western Ohio. Its upper boundary is not always distinct, as the Hudson River shale that overlies it sometimes graduates into it in color and appearance; but as a rule the driller, without any geological prepossessions whatever, will divide the well section in his record so as to show about 300 feet of black shale at the bottom of the column or immediately overlying the Trenton limestone. This stratum holds its own as far as the southern central counties. In the wells of Springfield, Urbana and Piqua, it is found in undiminished thickness, but apparently somewhat more calareous in composition. From these points southward, the black shale thins rapidly. It is apparently replaced by dark-colored limestone bands known as pepper and salt rock by the driller. No great falling off in black shale appears in the Dayton well, but at Middletown the driller reported a sharp boundary between gray shale 310 feet thick, and black shale 100 feet thick—the latter directly overlying the Trenton limestone. At Hamilton the same driller reported the boundary still distinct, but the black shale was here reduced to 37 feet, according to his record.

From these and similar facts it appears that the Utica shale is much reduced and altered as it approaches the Ohio Valley, and is finally lost by overlap of the Hudson River shale in this portion of the state and to the southward. Considerable discussion has been indulged in over the question, what part of the series exposed at Cincinnati and its vicinity is the Utica shale?

The answers have all agreed thus far at least, that if any part is to be counted Utica, the 50 to 100 feet of greenish blue shale overlying the Point Pleasant or Trenton limestone must be so considered. In this division, certain fossils occur that are also found in the Utica shale of New York, but that are not characteristic of it in the sense of being limited to it. Of these fossils the trilobite *Triarthrus Beckii* is an example. It is found in the Trenton, Utica and Hudson River formations

of New York, though most abundantly in the Utica. Certain new species of shells belonging to the genus *Leptobolus*, which contains the most characteristic Utica forms, are also found in the lower beds at Cincinnati. But associated with these semi-characteristic fossils were many of the ordinary fossils of the Hudson River series. Until the new facts from northern Ohio came to light the arguments for recognizing the beds in question as Utica shale, were fairly strong, but at present it does not seem probable that these greenish blue shales were formed contemporaneously with the black Utica shale of northern Ohio. The Cincinnati axis was already begun, and by its advancing border in southern Ohio the growth of the Utica shale was checked in this direction, and the record became defective in the Ohio Valley by the more or less complete exclusion of this element from the scale. The discussion of these questions will be taken up more fully in the account to be given of the Cincinnati wells.

3. The Hudson River Group.

The very important and interesting series now to be described appears in all the previous reports of the Geological Survey under another name, viz., the Cincinnati group. It is unnecessary to review here the long discussions pertaining to the age of this series, or the grounds on which the changes in the name by which it is known have been based. The return to the older name here proposed, is necessitated by the discoveries recently made in our underground geology, to which reference has already been made. So long as the Utica shale was held to be included in the section at Cincinnati but without distinct or recognizable boundary, so long could the maintainance of the name Cincinnati group be justified. It was held to cover two divisions of geological history which were practically inseparable, and therefore the name of either would be inapplicable to the compound series; but since it has been demonstrated or at least made highly probable, that the Utica shale forms either no part, or but a very small part, of the section at or near Cincinnati, there is no longer any reason for continuing the name Cincinnati group. It becomes a synonym and must be rejected as unnecessary and indefensible.

The Hudson River group in southwestern Ohio consists of alternating beds of limestone and shale, the latter of which is commonly known as blue clay. The proportion of lime and shale vary greatly in different parts of the series. The largest percentage of shale occurs in the 250 feet of the series that begin 50 or 75 feet above low water at Cincinnati. The entire thickness of the series in southwestern Ohio is about 750 feet.

The division of the series into lower and upper is natural and serviceable. The lower is known as the Cincinnati division and the upper as the Lebanon division. The Cincinnati division has a thickness of 425 to 450 feet, and the Lebanon division a thickness of about 300 feet. The divisions are separated on both paleontological and stratigraphical grounds. Both divisions abound in exquisitely preserved fossils of Lower Silurian time; and in fact the hills of Cincinnati and its vicinity have become classical grounds to the geologist on this account.

As the series takes cover to the northward and eastward it retains for a time the same characteristics already described, but as it is followed further it rapidly becomes less calcareous. The limestone courses are thinner and fewer, and inasmuch as they resist or delay the drill but little in its descent, the entire series comes to be counted shale. One other fact needs to be mentioned. The shale at certain points, and especially on the western border, often grows dark in color so that the boundary between this and the underlying Utica division is somewhat obscure.

The entire interval in such circumstances may pass with the driller as black shale. The shale of this series are thinnest in this part of the state, the entire measure running as low as 300 feet, or even less. To the eastward the greenish blue element already named, is always found. The Hudson river shales are fossiliferous, as the fragments of corals and shells brought up in the drillings abundantly testify. A few of the fossils are identifiable.

The Hudson River group occupies in its outcrop about 4,000 square miles in southwestern Ohio, but it is doubtless coextensive with the limits of the state. The shales of the series contain in outcrop large quantities of phosphates and alkalies, and the soils to which they give rise are proverbial for their fertility.

The presence of these fine-grained and impervious shales in so many separate beds forbids the descent of water through the formation. In its outcrop the formation has no water supply, and, as found by the driller, it is always dry. It gives rise to frequent "blowers" or short-lived accumulations of high-pressure gas when struck by the drill, as has been found in the experience in many towns of western Ohio within the last two years, and it also yields considerable amounts of low-pressure shale gas, which proves fairly durable. In a single instance it has given rise to high-pressure gas, but the supply was not of long duration.

4. The Medina Shale.

A stratum of non-fossiliferous shale, often red or yellow in color and having a thickness of ten to forty feet, directly overlies the uppermost beds of the Hudson River group at many points in southwestern Ohio. In the Report of Progress for 1869, Geology of Ohio, page 148, the suggestion was made that this red band represents the Medina epoch, the position of the stratum and its color being the grounds of reference. The same view was further urged by Newberry in Geology of Ohio, Vol. 1, page 126, but no additional reasons for assigning the stratum to this position have been found until within the last year. The occurrence of 50 to 150 feet of red shale in most of the recent deep borings in northwestern Ohio at exactly the place in the general column where the Medina should be, and so much nearer to the known outcrops of the formation that its continuity with these was hardly to be questioned, this fact, taken in connection with the occurrence of like beds of red shale holding the same relative position in several deep borings in the central portions of the state, serves to confirm the halting reference of 1869, and to give warrant for counting the Medina epoch duly represented in the outcropping strata of southwestern Ohio. It occurs here only in included sections, its thin and easily eroded beds never being found as surface formations for extensive areas. There is good reason to believe that the Medina formation is coextensive with the limits of the state, except in the regions from which it has already been removed.

The red color of the shales is quite persistent, but there are many well-records in which this color does not appear. This is especially true in Allen county, and to the westward and northwestward from Lima. Blue shales alternate with the red in the eastern sections. In the western they replace the latter. Thin beds of sandstone are found in the Medina, especially to the eastward. Small pebbles occur in some of these beds.

5. The Clinton Limestone.

The Clinton group of New York appears as a surface formation in Ohio only in the area already named. It forms a fringe or margin of the Cincinnati group through eight or ten counties, rising above the soft and easily eroded rocks of this series, and of the previously named Medina shale in a conspicuous terrace. It is everywhere a well-characterized limestone stratum. It is highly crystalline in structure, and is susceptible of a good polish. In some localities it is known as a marble. A considerable part of it, and especially the upper beds, are

almost wholly made up of crinoidal fragments. In thickness, it ranges between ten and fifty feet. Its prevailing colors are white, pink, red, yellow, gray and blue. At a few points it is replaced by the hematite ore that is elsewhere so characteristic of the formation. The ore is generally too lean and uncertain to possess economic value, but it was once worked for a short time and in a very small way in a furnace near Wilmington, Clinton county.

The limestone contains a notable quantity of indigenous petroleum throughout most of its outcrop, but no very valuable accumulations of oil or gas have been found in it thus far. It is the source of the low-pressure gas of Fremont (upper vein), and also of the gas at Lancaster from 1,962 feet below the surface, and at Newark from 2,100 feet below the surface. In fact, a small but fairly persistent flow is maintained from this horizon in several of the gas-producing districts of Northern Ohio. In a single instance in Wood connty it is proving itself an oil rock. A well near Trombley, drilled to this horizon, has been flowing twenty to thirty barrels of oil for a number of months, the oil being referable to this formation.

In outcrop the stratum is quite porous as a rule, and the water that falls upon its uncovered portions sinks rapidly through them to the underlying shale (Medina), by which it is turned out in a well-marked line of springs.

In composition, the limestone, in its outcrops in southern Ohio, is fairly constant. All of its most characteristic portions contain eighty to eighty-five per cent. of carbonate of lime, and ten to fifteen per cent. of carbonate of magnesia. At a few points, however, it is found as the purest carbonate of lime in the state. Under cover, to the northward, it is much more magnesian in composition, being indistinguishable from the Niagara. It also becomes shaly and changeable in character at many points. As it becomes shaly the thickness is much increased.

It is everywhere uneven in its bedding, being in striking contrast in this respect with the formations below it and also above it. The beds are all lenticular in shape, and they extend but a few feet in any direction. They seldom rise to one foot in thickness.

The uneven bedding, the crystalline and crinoidal characters, the high colors, and particularly the red bands and the chemical composition, combine to make the Clinton limestone an exceedingly well-marked stratum throughout southwestern Ohio, and from the hints yielded by the drill in northwestern Ohio, it seems to have something of the same character there, especially so far as color is concerned. It becomes more shaly and much thicker to the eastward. It carries bands of red shale

almost universally throughout the northern central and central parts of the state.

The limestone is directly followed at a number of points in the territory occupied by it, by a stratum of very fine-grained, bluish-white clay, containing many fossils distributed through it, the fossils being crystalline and apparently pure carbonate of lime. Some of them are characteristic of the formation elsewhere as *Orthis circulus*, *Atrypa nodostriata*, *Rhynchonella neglecta*, etc., while others are known only in this bed as *Triplesia Ortoni*. A similar bed of white clay is reported at the same horizon, by the drillers in northern Ohio, and the drillings show the presence of fossils of the same characters. This clay seam can be designated the Clinton clay, but it merges in and is indistinguishable from the lowest element in the next group. The Clinton, in its outcrops, is entirely confined to southern Ohio.

6. The Niagara Group.

The Clinton limestone is followed in ascending order by the Niagara group, a series of shales and limestones that has considerable thickness in its outcrops, and that occupies about 3 000 square miles of territory in Ohio. The lowest member is the Niagara shale, a mass of light-colored clays, with many thin calcareous bands. It has a thickness of 100 feet in Adams county, but it is reduced rapidly as it is followed northward, and in Clarke and Montgomery counties it is not more than ten or fifteen feet thick. Still further to the northward, as appears from the records of recent drillings, the shale sometimes disappears entirely, but in the great majority of wells, especially in Hancock and Wood counties, it is a constant element, ranging from five to thirty feet. Wells are often cased in this shale, but a risk is always taken in doing so.

In Montgomery, Miami and Greene counties the shale contains in places a very valuable building stone, which is widely known as the Dayton stone. It is a highly-crystalline, compact and strong stone, lying in even beds of various thickness, and is in every way adapted to the highest architectural uses. It carries about ninety-two per cent. of carbonate of lime. The Niagara shale is, as a rule, quite poor in fossils. It is apparently destitute of them in many of its exposures.

The limestone that succeeds the shale is an even-bedded, blue or drab, magnesian stone, well adapted at many points to quarrying purposes. It contains many characteristic fossils of Niagara age, such as *Spirifera Niagarensis*, *Pentamerus oblongus*, *Rhynchonella Tennesseensis*, *Calymene Niagarensis*, etc., etc. It is known in Ohio by various local names, derived from the points where it is worked. There are several subdi-

visions of it that are unequally developed in different portions of the state. Like the shale below it, this member is thickest in southern Ohio. It cannot be recognized as a distinct element in the northern part of the state either in outcrop or in drillings. It may be that its horizon is not reached in any natural exposures of the formation in this part of the state.

The uppermost division of the formation is the Guelph limestone, which differs very noticeably in several points from the Niagara limestone proper. It obtains its name from a locality in Canada, where it was first studied and described. It has a maximum thickness in southern Ohio of 200 feet. It differs from the underlying limestone in structure, composition and fossils. It is either massive or very thin-bedded, rarely furnishing a building stone. It is porous to an unusual extent. It is generally very light in color, and is everywhere in the state nearly a typical dolomite in composition. It yields lime of great excellence for the mason's use.

It is exceedingly rich in fossils, containing a large number that are thoroughly characteristic of the formation. Among the more conspicuous of these may be named *Trimerella* and *Monomerella*, *Megalomus Canadensis*, *Saccocrinus*, various species, *Eucalyptocrinus cornutus*, *Caryocrinus ornatus*, *Tremanotus alpheus*, etc., etc.

Unlike the previously named divisions of the Niagara, the Guelph limestone is as well developed in northern as in southern Ohio in all respects. Not more than forty feet are found in its outcrops here, but the drill has shown several times this amount of Niagara limestone without giving us all of the data needed for referring the beds traversed to their proper subdivisions. What facts there are seem to point to the Guelph as the main element in this underground development of the formation in this portion of the state.

The Hillsboro sandstone is the last element in the Niagara group. It is found in but few localities, and its reference to the Niagara series in its entirety is not beyond question. In Highland county it has a thickness of thirty feet in several sections. It is composed of very pure, even-grained, sharp silicious sand. Other deposits of precisely the same character are found in the two next higher limestones of the scale at several points in the state. One of these deposits is interstratified with the Waterlime in Scioto, Wood and Lucas counties, and others are imbedded in the Corniferous limestone in central Ohio. The latter have been referred to the Oriskany period, but, strictly speaking, this reference is inadmissible, inasmuch as normal Corniferous limestone with its most characteristic fossils is found below as well as above the sandstone. The subject will be further considered on a succeeding page.

The Hillsboro sandstone is sometimes built up above all the beds of the upper Niagara limestone, but again, it is, at times, interstratified with the beds of the Guelph division. In the latter case it is itself fossiliferous, but when found alone it seems destitute of all traces of life. These sandstones in the limestone formations suggest in their peculiarities a common origin. They all consist of unworn and nearly perfect crystals, in considerable part. Their occurrence in outcrops becomes a matter of interest to us, now that we are called to interpret the varied records of deep drillings throughout the state. What would otherwise be altogether anomalous sections may be rendered intelligible by the known presence of such elements in our series.

The Salina Group.

This group has appeared in all the recent sections of the rocks of the state, but in the light of facts recently obtained, it can no longer be counted a distinct or recognizable element in the Ohio scale. Newberry gave it the place it has lately held in the column, and assigned to it a thickness of forty feet. To it he referred the plaster beds of the Ottawa county peninsula, and certain impure limestones of Put-in Bay Island. He also recorded the disappearance of what he counted the same stratum a few miles south of the lake shore in a shaly bed that rests immediately upon the Niagara limestone.

These identifications are, however, incompatible. The limestones of Put-in Bay and the plaster beds of the peninsula do not directly overlie the Niagara limestone, but on the contrary are separated from it by several hundred feet of the brown, even-bedded, sparingly fossiliferous magnesian limestone that we call the Lower Helderberg limestone or Waterlime. In other words, the plaster beds of Gypsum are buried in the middle, or above the middle, of this great sheet of limestones, instead of being planted at its base. The reference of this formation to the Salina was rendered probable at the time from the fact that all the gypsiferous formations of New York were then counted of Salina age. It has since been proved by Prof. S. G. Williams, of Ithaca, that gypsum is also contained in the Waterlime of central New York, and it is in like situations that the Ohio quarries are found.

The Salina period is an important one in the New York scale, a thousand feet of deposits being credited to it, and there are probably some deposits in Ohio that are contemporaneous with it; but it cannot be the gypsum-bearing beds of Ottawa county, unless it is made to take in at least one-half of the entire formation that we now call Waterlime. This gypsiferous series proves to be of considerable thickness and to be

wide-spread. It is struck in scores of the wells that are being drilled in northern and central Ohio. In Sandusky, gypsum was found in quite pure and thick beds, through several hundred feet of the strata through which the drill passed, and in the deep well at Cleveland both rock-salt and gypsum (anhydrite) were found in considerable deposits. Notable deposits of gypsum, also, have been found in the deep wells of Columbus, Newark, and many other towns. Salt and gypsum are geological accidents, and cannot well be used in determining the geological order of regions that are separated by intervals of hundreds of miles.

The reference of distinct portions of our geological scale to the Salina period must accordingly be discarded for the present, at least.

7. The Lower Helderberg or Waterlime Formation.

The interval that exists between the Niagara and the Devonian limestones is occupied in Ohio by a very important formation. This formation was first separated from the previously undivided mass of the Cliff limestone by Newberry in 1869. He found and identified its fossils, and showed by means of them, and by the position of the stratum in our series, that the rocks of this interval are the equivalents, in part at least, of the Waterlime of the New York scale. The Waterlime of New York is classed by most geologists with the Lower Helderberg series; but Hall counts it the upper member of the Salina Group, a reference that seems likely to be ultimately considered the true and proper one.

The name is unhappily chosen. Strictly applicable to only an insignificant fraction of the beds of this series in New York, we are still obliged to apply the designation Waterlime, with its misleading suggestions, to all deposits of the same age throughout the country.

Though the last to be recognized of our several limestone formations, the Waterlime occupies a larger area in Ohio than any other, its principal developments being found in the drift covered plains of the northwestern quarter of the state. It has also a much greater thickness than any other limestone, its full measure being at least 600 feet, or twice the greatest thickness of the Niagara limestone.

It can be described as, in the main, a strong, compact, magnesian limestone, poor in fossils, and often altogether destitute of them for considerable areas, microscopic forms being excepted. It is, for the most part, drab or brown in color; but occasionally it becomes very light-colored, and again it is often dark-blue. It is brecciated throughout much of its extent, the beds seeming to have been broken into sometimes small and sometimes large angular fragments after their harden-

ing, and then to have been recemented without further disturbance. In addition to this, it contains an immense amount of true conglomerate, the pebbles, many of which are bowlders rather than pebbles, being all derived from the rocks of the same general age. The surface of many successive layers at numerous points are covered with suncracks, thus furnishing proof of having been formed in shallow water near the edge of the sea. In such localities, the beds are usually quite thin, and are also impure in composition. In these respects, it suggests the conditions of the Onondaga Salt Group of New York. These features are very characteristic ones. A rude concretional structure is also quite distinctive of the beds of this age. The Waterlime in Ohio everywhere contains petroleum in small quantity which is shown by the odor of freshly broken surfaces. No noteworthy accumulations of oil or gas have thus far been found within it. At some points, it carries considerable asphalt, distributed through the rock in shot-like grains, or in sheets and films. Thin streaks of carbonaceous matter traversing the rock parallel to its bed planes are one of the constant marks of the stratum in Ohio. It is generally thin and even in its bedding; but in some localities it contains massive beds. At some points, it is remarkable for its evenness, and great value is given to the formation on this account, when combined with other qualities already named. It is frequently a nearly pure dolomite in composition, and accordingly, it yields magnesian lime of high quality and is extensively burned in the state, rivaling in this respect the Guelph beds of the Niagara.

In southern Ohio, it has a maximum thickness of 100 feet, and here it reaches its highest quality in all respects; but in central and northern Ohio it attains the great thickness previously reported. There also, it contains several distinct types of limestone rock. A considerable part of it is very tough, strong, dark-blue limestone, while other portions are white, porous and soft.

Its fossils are referable, in type at least, to the age of the Waterlime, as already stated. The most characteristic forms are the crustacean named *Eurypterus*, which was found by Newberry on the islands of Lake Erie, and which has not been reported elsewhere in the state; and the bivalve crustacean *Leperditia*. There are points in the state, however, where the stratum contains a considerable fauna, and perhaps ground may be found for removing some of the higher beds that are now included in it into a distinct division, viz., the Shaly limestone of the Lower Helderberg series. Greenfield, Highland county, and Lima may be named as localities near which especially fossiliferous phases of the Waterlime can be found.

The line of junction between the Niagara and Waterlime is sometimes obscure, and no means are at hand for drawing sharp lines of division.

All that has been thus far said applies mainly to the formation as found in outcrop; but well-reamings brought up from considerable depths at various points in the state render it certain that the principal features now given mark the formation below ground, as well as above. There is no reason to doubt that the Waterlime has as wide a distribution in the subterranean geology of Ohio as the formations already described. It is to be found in every part of the state in which it is due.

This formation has come into new prominence through the revelations of the drill within the last year. In regard to no other element in the state series have the geologists been so wide of the mark as in regard to the Lower Helderberg formation. What belongs to it was taken from it and given to a stratum that has no existence in the state; and it was credited with but one-sixth of its real thickness. Its outcrops ought to have shown that it has a greater thickness than was assigned to it, since it covers several scores of miles in an east and west line. It demands a large amount of additional investigation to put it in order; and to secure such a mastery of it as to be able to determine from an inspection of any outcrop what place it holds in the general series will be a valuable service to the geology of the state. Winchell established approximately one horizon in it which promises to be of some service, namely, the horizon of the Tymochtee Slate, a bed of dark-blue shaly limestone that is found in outcrop in the Tymochtee Creek near Carey, Wyandot county. It is below the middle of the formation and probably within 100 to 200 feet of the Niagara limestone. A few other facts can be added that bear upon the same point. The excessively hard and strong dark-blue impure limestone of Allen, Hardin and Hancock counties and some adjoining regions, which often has its surface conspicuously marked with suncracks, belongs to the middle portion of the formation, but probably rather above than below the middle. A single other element remains to be inserted in the Lower Helderberg column, the interpolation of which at this point will occasion surprise to all who are conversant with the current statements in regard to our geological scale.

The Sylvania Sandstone.

A remarkable deposit, or rather series of deposits, of extremely pure glass sand has long been known in Lucas and Wood counties of Northern Ohio and in adjacent territory. The two best known deposits are those

of Sylvania and Monclova, which respectively lie ten miles northwest and west of Toledo. Other similar deposits are known in Wood county; and it is probable that the sand deposits of Monroe county, Michigan, belong to the same horizon. The Sylvania sand has been referred by Newberry in connection with several other sandstone deposits, some of which are on the same horizon with it, and some of which belong to quite distinct and widely separated horizons, to the Oriskany sandstone. The first account of the Sylvania sandstone was given by Mr. G. K. Gilbert in the description of the geology of Lucas county, Geology of Ohio, Vol. 1, page 576. Mr. Gilbert, however, does not assign it to the Oriskany, but distinctly includes it with the Corniferous limestone. His reasons for placing it within the last-named formation appear in his statements. He reports fossils of the Corniferous limestone in a bed that underlies the sand. The section that he finds here from this lower fossiliferous bed to the summit of what he considers the Corniferous formation includes 164 feet of rock.

The facts, as now seen, are as follows: The sandstone, twenty or more feet in thickness, seen in the Sylvania quarries, rests upon beds of normal Waterlime, which are exposed a few rods to the eastward. The rocks are very sharply inclined here, descending in an almost due west direction at the rate of one foot to seven, as determined by the clinometer from numerous exposures. These quarries mark, in fact, the northernmost extension of the Findlay break, and the abrupt descent of the rocks to the westward is probably nearly continuous from here to Findlay. *The rocks overlying the sandstone*, as seen in extensive quarries from which hundreds of cords of stone have recently been removed, *are unmistakable Waterlime*, containing all the characteristic marks of the formation, its chemical composition, its bedding, its bituminous character, and its fossils. Further on, the conglomeratic phase of the Waterlime appears. There is nothing in the whole formation more characteristic than this. At the end of the series eighty rods to the westward from the sandstone quarry, a few feet of undoubted Corniferous limestone occur, rich in the fossils of the formation and true to its chemical composition. All this is absolutely unequivocal and decisive. The Sylvania sandstone lies nearly or quite 200 feet below the Corniferous limestone. As to the fossils that Mr. Gilbert reports below the sandstone in his layer No. 1 (l. c.), nothing can now be said, from the fact that this bed has not been rediscovered. The statements of so careful and discriminating an observer as Mr. Gilbert must be set aside, if at all, with great hesitation; but the facts as now seen are so absolutely decisive that the question in regard to the sandstone cannot be considered an open one. If a layer containing such fossils occurs

below the sandstone, then this fossiliferous layer must be taken into the Lower Helderberg limestone, whatever its contents may be. It will be borne in mind that fish remains have already come from lower horizons than this in the rocks of central Pennsylvania. The thickness of the so-called Corniferous in the Sylvania section made by Mr. Gilbert would in itself lead us to discard the identification, because this formation nowhere else in Ohio passes a limit of seventy-five feet. Instead of being more than double here it has in reality but a fraction of its usual thickness; and the fossils that are crowded together in the fifteen feet of true Corniferous limestone that occur in the section on its western limit belong to both bottom and top of the limestone when found in its full development. In other words, instead of being greatly expanded in the Sylvania section, the Corniferous limestone is greatly reduced here. The Monclova or Holland sandstone occupies the same position in the series as the Sylvania sandstone does. The Grand Rapids sandstone of Wood county probably belongs to the same level. Perhaps, also, it is the Sylvania sandstone that appears in the thirty feet bed of sharp and pure sand that is reached in the deep well of the Cleveland Rolling Mill Co., at a depth of about 2,000 feet from the surface, and under 300 feet of limestone. That the Upper Helderberg limestone should expand between Sandusky and Cleveland from 75 to 300 feet and thus make this thirty feet sandstone the equivalent of the Oriskany is hard to believe; but it might retain its normal measure of seventy-five feet, and the balance of the 300 feet could be easily provided for by the Lower Helderberg limestone. The sandstone itself is of precisely the same character as that found in the Sylvania quarries.

That there is another sandstone of similar character with the Sylvania sand included in the Corniferous sand, is beyond question. This formation will be treated under the next section. The Sylvania sand can henceforth be counted an Upper Silurian sandstone and a part of the Lower Helderberg series.

8. The Upper Helderberg Limestone.

All of the limestone of Devonian age in Ohio has been referred, by Newberry, to the Corniferous limestone, and this term is in general use at the present time. It may be questioned whether it is wise to break in upon this here, but inasmuch as several geologists hold that the Devonian limestone of Ohio covers more than the single epoch known as Corniferous in New York, a more comprehensive term, viz., the Upper Helderberg limestone, is counted preferable. A two-fold division of the series is possible and proper in Ohio, the division being based on both

lithology and fossils. The divisions are known as Lower and Upper Corniferous, or as Columbus and Delaware limestones. For the upper division, the term Sandusky limestone is sometimes used. In central Ohio, at a few points, there is a marked contrast between the lower and the upper beds, the latter being thin and shaly, non-fossiliferous in the main, and interrupted with frequent courses of black flint. This phase is seen at the State quarries near Columbus. Generally, however, both divisions are calcareous and fossiliferous, and the differences consist in changes of color and composition, in thickness of the several beds and in the distribution, and also in the kinds of fossils present.

The maximum thickness of the Upper Helderberg series in Ohio, so far as present records show, is 75 to 100 feet.

Included in the lower beds of the limestone there are, at many points, deposits of sharp sand of the same character as the deposits already described under the names of Hillsborough sandstone and Sylvania sandstone. These beds may be known as the West Jefferson sandstone, one of the localities at which the sand is found being near this village. This Upper Helderberg sandstone is not Oriskany in age. It nowhere underlies the Corniferous lime-tone, but is always underlain by it and interstratified with it. It attains a thickness of but few feet at most, and is nowhere worked for economic uses except upon the smallest scale.

In chemical composition, the Corniferous limestone is easily distinguished from all that underlie it. It is much less magnesian than the other members of the Cliff limestone of Ohio, already described. It is never a true dolomite in composition, as the Waterlime and Niagara limestones almost always are. The carbonate of magnesia ranges in it from two to thirty-five per cent., reaching the latter figure in but few cases. The composition of the typical, heavy-bedded lower Corniferous may be taken as seventy per cent. carbonate of lime and twenty-five per cent. carbonate of magnesia. The higher beds of the Columbus stone regularly yield ninety-one to ninety-five per cent. carbonate of lime. The upper division, or the Delaware stone, is much less pure in central Ohio than the lower, a notable percentage of iron and alumina, as well as silica, generally being contained in it. It is, therefore, seldom or never burned into lime. In northern Ohio, on the contrary, it is often found very strong and pure limestone.

Both divisions, but particularly the lower one, carry occasional courses of chert, that detract from the value of the beds in which they occur. The chert is found in nodules which are easily detached from the limestone for the most part. In some conditions in which the chert occurs, fossils are found in it in a remarkably good state of preservation.

The percentage of chert and flint in any section would be considerable, and this fact must be borne in mind in the analysis of drillings from bore holes that penetrate the formation.

The beds of the lower division are prevailingly light-colored, ranging from whitish to gray, drab and brown. The upper beds are oftener blue than otherwise.

The beds of the lower division are, as a rule, much thicker than those of the upper. The bottom courses of all are sometimes quite massive. In the State quarries they are not less than five feet thick. In the upper division the separate courses seldom reach a thickness of one foot.

Throughout the entire formation Devonian fossils abound in great variety and in great numbers. They are often found in an excellent state of preservation. The oldest vertebrate remains of the Ohio rocks are found in the Corniferous limestone, a fact which gives especial interest to it. The uppermost bed of the lower or Columbus division is, in many places, a genuine "bone bed"; the teeth and plates and spines of ancient fishes, largely of the nearly extinct family of ganoids, constituting a considerable portion of the substance of the rock. Corals of various types are also especially abundant and interesting in this limestone. In fact, the formation is the most prolific in life of any in the Ohio scale. At a few points in central Ohio, the upper division has been found in a shaly state and carrying characteristic fossils of the Marcellus slate. This fact was first noticed in its true significance by Whitfield.

9. The Hamilton Shale.—Olentangy Shale?

Under this head Newberry has recognized fifteen to twenty feet of highly fossiliferous blue shale, intervening between the Corniferous limestone and the black shale. He finds it at only one or two points in northern Ohio, and notably at Prout's Station, seven miles south of Sandusky. The fossils found here are all of Hamilton age, unmingled with those of the underlying Corniferous limestone.

On stratigraphical grounds it seems probable that the Olentangy shale of Professor N. H. Winchell is the extension and equivalent of Newberry's Hamilton shale. The Olentangy shale is a bed of blue calcareous shale, twenty or thirty feet in thickness, holding exactly the position of the northern Ohio stratum, but is almost destitute of fossils. It is found in a few sections of three or four counties in central Ohio. In the well-driller's record it would seem likely to be classed with the limestone below rather than with the black shale above, and, as already suggested, the incorporation of this element

might easily serve to expand the measurement of the limestone by a small amount.

With this formation the great limestones of Ohio were completed. While they are built into the foundations of almost the entire state, they constitute the surface rocks only in its western half. The Upper Silurian and Devonian limestones of our scale, which were formerly known as the Cliff limestone, have an aggregate thickness of 750 to 1150 feet where found under cover, and though differences exist among them by which, as has already been shown, they can be divided into four or more main divisions, there is still no reason to believe that any marked change occurred in the character of the seas during the protracted periods in which they were growing. The life which these seas contained was slowly changing from age to age, so that we can recognize three or more distinct faunas or assemblages of animal life in them. Differences are also indicated in the several strata as to the depth of the water in which they were formed, and as to the conditions under which the sedimentary matter that enters into them was supplied, but no marked physical break occurs in the long history. No part of the entire series indicates more genial conditions of growth than those which the Devonian limestone, the latest in order of them all, shows. It is the purest limestone of Ohio. Foot after foot of the formation consists almost exclusively of the beautifully preserved fragments of the life of these ancient seas. In particular the corals and crinoids that make a large element in many of its beds could only have grown in shallow but clear water of tropical warmth.

The change from the calcareous beds of this age to the next succeeding formation is very abrupt and well marked, as much so, indeed, as any change in the Ohio scale.

10. The Ohio Shale.

(Cleveland Shale, Erie Shale, Huron Shale, of Newberry.)

A stratum of shale, several hundred feet in thickness, mainly black or dark-brown in color, containing, especially in its lower portions, a great number of large and remarkably symmetrical calcareous and ferruginous concretions, and stretching entirely across the state from the Ohio Valley to the shores of Lake Erie, with an outcrop ranging in breadth between ten and twenty miles, has been one of the most conspicuous and well-known features of Ohio geology since this subject first began to be studied. It separates the great limestone series already described, which constitutes the floor of all of western Ohio, from the Berea grit, which is the first sandstone

reached in ascending the geological column of the state, and which, in like manner, may be counted the floor of all of Eastern Ohio. By the geologists of the first survey it was designated as the *Shale Stratum* or the *Black Slate.* It will be treated in this report under the designation *Ohio shale.* Newberry divided it into three divisions, which he named respectively the Cleveland, the Erie and the Huron shale. He based the separation of the hitherto undivided mass in part upon the colors of the proposed divisions, the Cleveland and the Huron being counted black shales, and the Erie greenish-blue. The names Huron and Erie were unfortunately chosen, for both are liable to be confounded with current names of other geological formations. The name *Huron* was adopted from Winchell, but a very different range was assigned to it from that which its author originally claimed. Winchell's "Huron group," extends, in his own words, from the top of the Devonian limestones, "to the conglomerate above the gritstones of Huron county." It is thus seen to include Newberry's Huron, Erie, Cleveland and Bedford shales, together with the Berea grit and the Cuyahoga shale. It would have served the interests of geological classification much better to have replaced the term altogether than to have thus restricted it to a small fraction of what it was originally made to cover. The name is also likely to be confused with the *Huronian slates*, an older and well-established division of the Canadian system of rocks.

The Erie shale, in like manner, is sure to be confounded with the Erie clay, the older name of an important deposit of the Glacial epoch. Both shale and clay have their typical exposures in the same localities, and their outcrops are not dissimilar in appearance. It is not therefore surprising that the names should be confused in popular use.

But aside from these grounds of objection to the particular names employed, the classification referred to is itself inconsistent with our present knowledge of the shale formation. We have records by the score of wells drilled through the shale at many points in northern Ohio during the last few years, and we have also the results of continued study of the formation in its outcrops. The facts gathered from both of these lines of investigation, not only fails to confirm the three-fold division above announced, but they demonstrate the impossibility of applying to the shale formation any system of classification based upon the color of the shales. The further retention of the divisions above-named, is therefore a hindrance rather than a help in the study of our geology. It misleads and confuses the student. The formation will be treated in this report under the name given to it by Shaler, Ky. Rep'ts, vol. III, p. 169.

10*a*. *The Lower Beds—Huron Shale.*

The Huron shale was defined by Newberry as a homogeneous mass of black, bituminous shale, 200 to 350 feet in thickness, directly overlying the limestone series already described. The objection to this definition is that there is no such mass of shale in Ohio. The mass on which the main statements pertaining to the Huron rest, and which furnishes nearly all of the examples instanced, is the shale stratum of central and southern Ohio, but this, as has been elsewhere shown (see Ohio Statistical Report, 1879, page 591), is not merely the bottom portion of the shale series of northern Ohio. It comprises all of the elements of the northern section. In other words, the so-called Huron shale of central Ohio is the Cleveland, Erie, Huron shale of northern Ohio. It is not a homogeneous mas of black shale, as it is commonly counted, but beds of blue or greenish-blue shale are frequently interstratified with the prevailing black beds, especially in the middle portion of the series. The top and bottom of the column are generally black shale, and the same thing is true in northern Ohio. These facts show the grounds on which the classification now referred to is based, but the objection to it is that no line of division can be drawn between the Huron and Erie or the Erie and Cleveland shales. The records of many drilled wells in northern Ohio show that alternations of black and blue shale recur not once only, but many times, in the formation. This alternation was recognized by Newberry as far back as 1872. He said at that time that the Huron shale in "its northerly outcrops is somewhat interstratified with the overlying Erie shale." (Geology of Ohio, Vol. 1, page 153). In other words, there is no line of division between the so-called formations. Since that time the facts bearing on the question have been greatly multiplied, and it is now apparent to all who keep acquainted with them, that the truth of geology demands the abandonment of the proposed three-fold division of the shale series. The Huron and Erie divisions are especially misleading, and therefore objectionable. These two terms, as they are used, cover different phases of the same formation. A single well record will be given to illustrate the character of the beds traversed by the drill in the lower half of the shale formation. The record of one of the wells drilled by Mr. J. H. Wade, of Cleveland, at his residence on Euclid Avenue, is as follows. The well-head is about seventy feet above the level of Lake Erie:

1.	Drift beds	300′
2.	Blue shale—dark	10′
3.	Dark or black shale	40′
4.	Dark shale	25′
5.	Dark shale, but lighter than No. 4	40′

6.	Gray shale, not very unlike No. 5	30′
7.	Black shale	10′
8.	Gray shale	185′
9.	Black shale—with sporangites	15′
10.	Gray shale	60′
11.	Black shale—sporangites abundant	15′
12.	Gray shale	65′
13.	Black shale—quite dark	55′
14.	Gray shale	80′
15.	Limestone.	

This record was kept with care and intelligence, and washed samples of the drillings which were saved verify it in all points. It will be seen that of the lowermost 500 feet of the shale formation in which the "Huron" must certainly be included, there are ninety-five feet of black shale in four divisions, against 400 feet of gray shale, also in four divisions. In the lowermost 300 feet, there are eighty-five feet of black against 215 feet of gray shale.

This is a fairly representative section. All of the carefully kept records of wells drilled through the shale formation show a similar alternation and thus forbid any two-fold or three-fold division of the series on the basis of color, at least, inasmuch as the color is not continuous in one horizon.

10*c*. *The Upper Beds—Cleveland Shale.*

The Cleveland shale has, it is true, a somewhat better chance for survival as a distinct division than the Erie or Huron. There is a tolerably distinct upper boundary for it, inasmuch as a belt of black shale generally underlies by 50 to 100 feet the Berea grit, by far the best landmark in this part of the scale, the interval being occupied by the Bedford shale, itself a well-characterized formation. In some sections, however, there is no black shale at the point where the Cleveland shale belongs, and in all sections the lower boundary of the formation is likely to be uncertain, unless the bottom of the first bed of black shale found below the Berea grit is in every case taken for the bottom of the Cleveland division, as Newberry's scheme requires. If this is done the Cleveland shale must stand for very unequal periods of geological time, as the uppermost black bed has a great range in thickness. It often falls to thirty feet and sometimes exceeds 200 feet. Newberry counts its normal thickness about fifty feet. It is probably the larger half of the great black shale of southern Ohio. It is this element that proves most persistent in the southerly extension of the black shale. The shale that covers the Lower Silurian limestone in central Kentucky, is the upper or Cleveland division, if the fossils can be relied on to settle the question.

The mineral basis of all these shales, whether black, brown, blue, gray or red, is essentially one and the same thing, viz., a fine-grained clay, derived from the waste of distant land. As supplied to the sea basin it was originally blue or gray, but a small percentage of peroxide of iron goes a great way in coloring such deposits red, and in like manner, organic matter in comparatively small amount gives them a dark or black color. The organic matter that colors these shales was probably derived in large part, as Newberry has suggested, from the products of growth and decay of sea-weeds by which these seas were covered like the Sargasso seas of our own day.

These organic matters seem to have accumulated along the shores and in shallow water in greater quantity than in the deeper seas. Hence, if the section of these shale deposits is taken near the old shore-lines, or where shallow water occurred, a larger proportion is black, than if the more central areas are examined. The only land of Ohio at this time was to be found in and along the Cincinnati axis, a low fold that had entered the state from the southward at the close of Lower Silurian time, and that had been slowly extending itself northwards through the succeeding ages. Southwestern Ohio was already above water, a low island in the ancient gulf. But the shales on their western outcrop, where they are largely black, are exactly equivalent in age to the alternating beds of black and blue shale, the latter being in large excess, that were forming at this time in the central parts of the basin, viz., in eastern Ohio. The color of the shales is, in this view, an accident, and cannot be safely used as a ground of division. The entire shale formation that we are considering seems to have been laid down without physical break or interruption. It must have required an immensely long period for its accumulation. This is shown not only by the fineness and uniformity of the materials which compose it, and which could not have been rapidly supplied, and by the great thickness of the formation in eastern Ohio, but also by the geological equivalents of the shale in the general column which furnish even more convincing proof as to its long continued growth. The Ohio shale, as Newberry has shown, is certainly the equivalent in the general scale of the Genessee slate, the Portage group and the Chemung group, the last named being itself a formation of great thickness and extent. In other words, the shales of our column bridge the interval between the Hamilton proper and the Catskill group, and in the judgment of some geologists, a wider interval even than that named above. As Newberry was the first to show, the oil sands of Pennsylvania are banks of pebble rock that are buried in the eastward extension of the Ohio shale, but which make no sign within our own limits.

But while definite boundaries for the division proposed cannot be laid down or applied within the shale formation, the facts that the top and the botton of the column, on their western outcrops, are prevailingly black, and that the middle of the series is oftener interrupted with light-colored beds are important ones in the history of the formation and deserve to be held in mind. From what has been already stated, it is seen that the composition and thickness of the shale series depend on where it is measured, whether on the border of the formation or in the interior of the old sea-basin in which it was formed. On the western border of the shales in southern Ohio, in Highland county, for example, the interval between the Upper Silurian limestone, on which the shales here rest by overlap, and the Berea grit is 300 feet. In Ross county, the same interval is nearly 400 feet. From both of the measurements, fifty feet must be deducted for the thickness of the Bedford shale in order to give the real thickness of the series now under consideration. In the sections named the shales are mainly black, although blue beds are still recognizable in the series. Passing northwards to Crawford county, the series is found about 450 feet thick. In Lorain county, at Elyria, it is about 950 feet, and at Cleveland, about 1,350 feet, while in Tuscarawas county the drill has recently descended through 1,860 feet of alternating beds of blue and black shale without reaching the bottom of the series, and in the Ohio Valley, at Wellsville, through 2,600 feet of shales without reaching bottom. In the last two sections, the blue shales decidedly preponderate, though the separate black beds can be counted by the score.

Fossils of the Shales.

The shales are for the most part poor in fossils, except in those of microscopic size. Banks representing scores of feet in the vertical column often fail to reward the most careful search with a single specimen of vertebrate, molluscan or articulate life, and so far as the unaided eye is concerned, they are almost equally barren of vegetable remains. Occasionally, however, fossiliferous bands are found, the contents of which serve to determine the geological age and equivalence of the portion of the series in which they occur.

A calcareous band near the bottom of the series at Bainbridge, Ross county, has yielded *Tentaculites fissurella*, a Hamilton fossil, and a new species of *Melocrinus*. A band of similar character near Defiance, and in the same part of the column, yield a *Chonetes*, probably *speciosa*, in abundance, but not in a very good state of preservation. Newberry reports from northern Ohio *Clymenia complanata*, *Chonetes speciosa*, *Ortho-*

eras aciculum and a *Leiorhynchus* in some of the lower beds of the shale. The first-named form is counted characteristic of the Portage group of New York.

The Erie shale of Newberry, embracing the central and most of the upper portion of the shale column, has yielded a somewhat larger list of fossils at a few points in Northern Ohio. Among them may be named *Spirifera disjuncta*, *Spirifera alta* and *Leiorhynchus mesacostalis*, from which Newberry determined the age of the beds to be Chemung, a determination of great importance in Ohio geology. In higher beds of the same blue shale, he found, at a few points, forms that are referred to the Sub-carboniferous, as *Syringothyris typa* and *Macrodon Hamiltoniæ*. Counting this the boundary line between the Devonian and Sub-carboniferous, he took what he deemed the first identifiable horizon above as the base of the last-named division, and accordingly drew the line at the base of the so-called Cleveland shale. This boundary is not a definite one, as subsequent investigations have shown, but the *top* of the upper black, or Cleveland shale, would answer fairly well for this purpose. It is the first mark that has any claims to persistency above the beds that hold the fossils already named. The fossils of the black shale proper offer no serious difficulty in the way of extending Devonian time to the upper limit of the stratum, and this boundary is consequently assumed as the only one that can be made practically serviceable.

Since making the division referred to above, Newberry has introduced a somewhat radical change into the whole system, by referring the Chemung group, and consequently its equivalent, the middle portion of the Ohio shale, to the Sub carboniferous, while the Portage beds are classed as Hamilton. (See Article *New York*, Encyclopedia Britannica, Vol. XVII.) There is no possibility of applying such a boundary to Ohio geology in a practical way. To apply it we should need to use a line which no man knows, viz., the lower boundary of the Erie shale.

The Cleveland shale, limiting the term to the highest bed of black shale in the series, and which is about fifty feet thick at various points near Cleveland, contains a few fossils, most of which are quite small. The most abundant and characteristic are the enameled scales, small and lozenge shaped, of a species of *Paleoniscus*. *Lingula* and *Discina* occur here in considerable numbers frequently. The microscopic fossils called *conodonts*, are also quite abundant.

The most striking and remarkable fossils, at once of the shale formation and of the entire scale of Ohio, remain to be named. They are the great fishes, which have been described under several genera and species, by Newberry. Some of them belong to the basal beds of the black shale (Huron), and others near the summit (Cleveland). The

first of the series were found at the centers of the great concretions that have been already named as characteristic of the formation.

Brief mention must be made of the vegetable fossils of the shales.

Fossil wood, derived from ancient pine trees of the genus *Dadoxylon*, is quite common in the lower beds (Huron). The wood is silicified and the original structure is admirably preserved. This wood is sometimes found, like the fish remains already noted, at the hearts of the concretions, but occasionally large sized blocks are found free in the shale. On account of its enduring nature it is often found in those beds of glacial drift that have been derived largely from the destruction of the shales.

Strap-shaped leaves, presumably of sea-weeds, are occasionally found upon the surfaces of the shale layers. Sometimes they form thin layers of bright coal which deceive the ignorant. Fossil rushes, of the genus Calamites, are also occasionally met with.

But the forms already named are of small account, so far as quantity is concerned, when compared with certain microscopic fossils that are, with little doubt, of vegetable origin, and which are accumulated in large amount throughout the black beds of the entire shale formation, composing, sometimes, a notable percentage of the substance of the rock, and apparently giving origin, to an important extent, to the bituminous character of the beds.

The leading forms of these microscopic fossils are translucent, resinous discs, ranging in long diameter from $\frac{1}{300}$ to $\frac{1}{2000}$ of an inch. Several varieties have already been noted, depending on the size, particular shape and surface markings of these bodies.

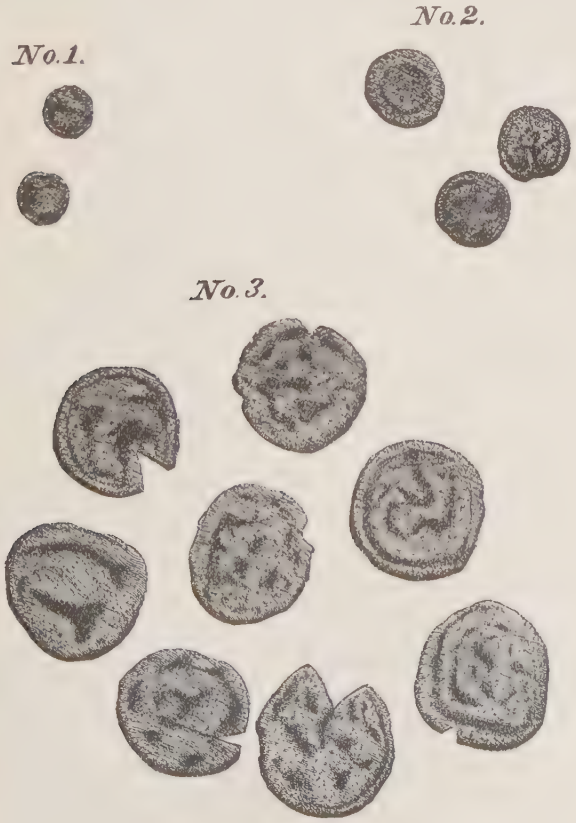
They were first discovered by Mr. B. W. Thomas, an expert microscopist, in the water-supply of Chicago, which is derived from Lake Michigan, and Mr. Thomas afterwards learned that they were washed by the water from the bowlder clays that compose the banks and bottom of the lake. He found the discs present in fragments of black shale, and also free in the clay which was derived from the comminution of the shale.

They were afterwards rediscovered in the black shale of Kettle Point, Lake Huron, by Professor, now Sir William Dawson, who published a description of the form here found under the name *Sporangites Huronensis*. Sir William counted them at this time the spore-cases of some lycopodiaceous tree.

Still later, they were found in the drillings of a deep well in Kingsville, Ashtabula county, Ohio, and this discovery was independent of those previously made. The drillings that contained them came from

about 1,000 feet below the surface. It was soon after learned that they are universally distributed throughout our black shales. The facts pertaining to them have of late been more widely published, and the attention of geologists in various parts of the world has been called to these and similar forms, and thus there is the promise of a speedy enlargement of our knowledge in regard to them. Sir William Dawson now considers the common forms to be the spore-cases of rhizocarps allied to *Salvinia* of the present day. This identification would refer these bodies to floating vegetation on the surface of the seas in which the shales were formed, and is thus directly in line with the sagacious interpretation of Newberry, who many years ago attributed the origin of these black shales to Sargasso seas.

In the accompanying cut, the appearance of the spores as seen opaque under the microscope, is shown. No. 1 represents forms that are $\frac{1}{200}$, No. 2, $\frac{2}{200}$, and No. 3, $\frac{4}{200}$ of an inch in diameter.



As illustrative of their universal distribution through the upper portion of the black shale, the following fact may be considered: fragments of the shale were taken from a section near the summit of the series in Ross county, at intervals of five feet for 100 feet of ascent. Every specimen showed the forms distinct, and on a number of them they were very abundant. In the lower beds they seem equally abundant, but few samples of the shale being found which will not reveal these fossils on proper examination. In many cases the spores are in a fragmentary state, though still determinable.

There is, however, in the shales a large amount of organic matter in which distinct structure is not found. The source of this larger portion of the bituminous matter of the shales would naturally seem to be the same vegetable growths from which the spores were derived. Such spores, as is well known, resemble resin in character, and are much more enduring than any other portions of the plant which produces them.

The fact that in the recurring beds of black shale, which are shown in the drillings of deep wells and elsewhere, the spores are always found and nowhere else, seems to connect them with the bituminous character of the beds in an important way. They, in connection with the vegetation which produced them, are apparently the source of this bituminous matter.

Composition of the Shales.

The chemical composition of the shales is seen in the following analysis, made from an ordinary sample of the black beds of the upper division (Cleveland, of Newberry), as found at Columbus: (*Lord.*)

Silicic acid	60.35
Alumina and oxide of iron	21.20
Carbonate of lime	2.95
Carbonate of magnesia	3.33
Volatile and organic matter	10.70
Moisture	70
Total	99.23

There is also a little sulphur that is in combination with the iron.

The most important element in the shales, so far as our present purposes are concerned, is their bituminous matter, for it is this, as will be shown on a subsequent page, to which we must refer the origin of the main supplies of the petroleum and natural gas in eastern Ohio.

No apology is needed for devoting so much time to this great shale formation. A clear idea of its structure and composition is essential to an understanding of the geology of oil and gas in Ohio.

11. The Waverly Group.

The important mass of sediments of Subcarboniferous age, which is known in Ohio and in some adjoining states as the Waverly group, comes next in the column. The name Waverly was given to these strata by the geologists of the first survey, from the fact that at Waverly, in the Scioto Valley, excellent sandstone quarries were opened in them, the products of which were quite widely distributed throughout central and southern Ohio, as far back as fifty years ago. Associated with the sandstone at this locality, and everywhere throughout the district, were several other strata that were always counted as members of the group by the geologists who gave the name. In fact, the boundaries were made definite and easily applicable. The Waverly group extended, by its definition and by unbroken usage in our early geology, from the top of the great black shale (Cleveland shale), to the Coal Measure conglomerate. This latter element was, in a part of the field, confused with the Waverly conglomerate, afterwards recognized and defined by Andrews, until a recent date, it is true, but the intent of the geologists is apparent, and many of their sections were complete and accurate. If the term Waverly is to be retained in our classification, and it bids fair to be, every interest will be served by recognizing and retaining the original boundaries. The departure from them that has been proposed has led already to great confusion. To make the Cleveland shale the base of the Waverly is, as has been already shown, to turn the entire shale stratum into a no-man's land. Aside from a few sections in northern Ohio, where an arbitrary limit was fixed for this upper division, there is no place in the state where a line can be drawn with any approach to certainty between Cleveland and Erie or between Erie and Huron. The plan was proposed before the true equivalence of the northern and southern ends of the column had been established. If the fact that the Cleveland shale of northern Ohio forms the top of the great shale of central and southern Ohio had been known, certainly no proposal would have been made to break into this undivided and indivisible series which had been held to underlie the Waverly group ever since the name was first applied.

11*a*. *The Bedford Shale.*

At Waverly and in its vicinity, numerous sections are afforded reaching from the black shale to the Waverly sandstone courses. This interval ranges from fifty to ninety feet in thickness, and its boundaries are generally very clear and distinct. It is occupied with shales, for

the most part light-blue or gray, but sometimes reddened with peroxide of iron in the lower portion. The latter phase is seen in the excellent section found at Piketon. These shales are thin-bedded, occasionally interrupted with fine-grained sandstone courses, and sometimes carrying very ungainly nodular masses of the same material, apparently shaped by a rough concretionary force. The beds are almost entirely destitute of fossils, aside from the burrows of sea-worms, which are found on the surfaces of most of the layers, and often with great sharpness of outline. All the layers, and especially the upper ones, are likely to be ripple-marked. In many instances, every sheet, for many successive feet, is marked with most symmetrical sculpturings of this sort.

This stratum, thus definitely characterized and bounded, received the name of the Waverly shale in the reports of the second Geological Survey, but in northern Ohio it was named by Newberry the Bedford shale, the equivalence of the strata not being at that time recognized. The latter name deserves to be universally accepted, being applied to a perfectly distinct and homogeneous formation. The stratum has precisely the same boundaries in northern that it has in southern Ohio, viz., the top of the great black shale (Cleveland) and the Berea Grit, and, in the main, precisely the same characteristics throughout its whole extent. The description of the stratum at Waverly applies to it at every other point, except that in northern Ohio at a few localities, and especially about Cleveland, there are fifteen to twenty feet of valuable stone included in it. This stone is even-bedded, very strong and durable, and it supplies a large quantity of flaggings, caps and sills, of the best grade. It is known as the East Cleveland, Euclid and Independence blue-stone. In northern Ohio, more of the formation is red-colored than in southern, and here it is the top of the formation rather than the bottom that is thus marked. In the lower beds of the Bedford shale fossils are, in northern Ohio, at a few points, abundant. They are of pronounced Subcarboniferous character, comprising *Syringothyris typa*, *Hemipronites crenistria*, *Chonetes Logani*, *Orthis Michelini*, *Spiriferina solidorostris*, and others of like association. None of these fossils have been reported south of the lake shore, but the stratigraphical relations of the shale are so clear and its lithological characteristics so pronounced, that there is not a stratum in our geological column that can be followed across the state in more easily demonstrated identity than this.

The only source of confusion pertaining to it is found in the records of the drillers of oil and gas wells. Where they reach this stratum under deep cover, it is generally counted in with the underlying Ohio shale. They pass from the sharp grit of the Berea into soft drilling

and count this element as but one of the many alternations in color that are found for many hundred feet in this part of the section.

11*b*. *The Berea Grit.*

We have reached in our review the Berea grit, the second element of the Waverly series, and not only the most important member of the series, but by far the most important single stratum in the entire geological column of Ohio. Its economic value above ground is great, but it is greater below. In its outcrops it is a source of the finest building stone and the best grindstone grit of the country, and when it dips beneath the surface it becomes the repository of invaluable supplies of petroleum, gas and salt-water. Its persistence as a stratum is phenomenal. Seldom reaching a thickness of fifty feet, its proved area in Ohio above ground and below, is scarcely less than 15,000 square miles, and beyond the boundaries of Ohio it extends with continuity and strength unbroken into at least four other adjacent states. As a guide to the interpretation of our series, and especially as a guide in our subterranean geology, it is invaluable.

The stratum was named by Newberry from the village of Berea, Cuyahoga county, where the largest and most important quarries of the formation are located. The name is the most appropriate that could have been selected for this stratum, and inasmuch as it has priority in all fields, it ought to be made to supersede all others.

From what has already been stated, it will be seen that the Berea grit and the Waverly quarry-stone of southern Ohio are one and the same sheet of sandstone. This identity was missed for a long while in the study of our geology, and a wrong order of arrangement found temporary acceptance. The resulting dislocation of our Subcarboniferous series brought into all our work upon it an element of confusion that is scarcely yet eliminated.

The Berea grit, as seen in outcrop, is a sandstone of medium grain in northern Ohio and of fine grain, from the center of the state southward. In northern Ohio, it contains one pebbly horizon over a considerable area, but the seam is thin and the pebbles are small. The stratum is sometimes false-bedded and sometimes remarkably even in its bedding-planes. Its main beds, or sheets, have a maximum thickness of six feet, but this is an unusual measure and is seldom reached. It ranges in thickness from 5 to 170 feet, and it very rarely fails altogether from the sections in which it is due.

Like the Bedford shale below it, it stands for an old shore-line, many of its surfaces being ripple-marked and worm-burrows abounding in its substance.

It is poor in fossils, but not entirely destitute of them. Several species of *Lingula* have been found in it, and a few lamellibranch shells also. Fishremains are the most conspicuous, but by far the rarest of the forms that it contains. Plant impressions are also unusual through most of the formation, but in northeastern Ohio there is a certain part of the stratum in which they are quite abundant. Throughout the great quarry district the material of which the stratum is composed is as clean sand as can be found on any sea beach. It grows more impure as its sand grows finer in grain in central, and especially in southern Ohio. A small percentage of clay is held in it at most points.

Under cover, it retains the same characteristics as to composition that it possesses above ground, ranging from fine to middling grain and very seldom showing pebbles. It has been proved by many hundred borings in southeastern Ohio during the last few years, and its composition there is almost as well known as in its outcrops.

11c. *The Berea Shale—Waverly Black Shale of Andrews.*

A bed of dark, often black shale, fifteen to fifty feet in thickness, makes the constant and immediate cover of the Berea grit throughout its entire extent in Ohio. The shale is highly fossiliferous. It contains *Lingula melie* and *Discina Newberryi*, almost everywhere, and at many points it is crowded with fish-remains, becoming, in fact, a true bone-bed. Species of *Cladodus*, *Orodus* and *Ctenacanthus* have been already described from it. *Conodonts* are very abundant in it. The bottom layer, which is especially rich in fossils, is very hard and stubborn, being composed of sand bound together with pyrites. It is often referred to the sandstone below rather than to the shale above, but its fossils and its bituminous character favor the reference here given, inasmuch as it marks new conditions in the history of these beds.

The stratum was first described by Andrews under the name of the Waverly black shale, the typical outcrop being found at Rockport, on the Ohio River, but about the same time Meek, who was studying its fossils in northern Ohio, introduced the designation Berea shale. (Pal., Vol. II, Plate XIV.) The latter name is clearly preferable and ought to obtain currency.

Its southern outcrops were mistaken by Newberry for the Cleveland shale, and the fossils found in it were credited to the latter stratum, and thus a good deal of confusion prevails in the published statements upon this part of the Waverly series.

In southern and central Ohio, and indeed in almost all of its outcrops, the boundaries of the Berea shale are sharp and perfectly distinct.

The Berea grit is its base, and the blue beds of the Cuyahoga shale overlie it. In Cuyahoga county, however, and eastward, the upper limit cannot always be fixed with precision, neither the dark-color nor the fossils of the shale disappearing abruptly, but both gradually diminishing. There are, however, twenty to forty feet that always deserve to be counted here.

When struck by the drill under cover the formation yields uniformly a similar line of facts to that already reported. Of the records of the many hundred wells that have been carried down to and below this horizon in southern Ohio and in adjacent territory during the last few years, there has not a single one been found that has failed to give a place to this little band of black shale. Its services in setting in order our Subcarboniferous geology have been simply invaluable. It is wanting at a few points in northern central Ohio apparently.

The Berea shale contains a larger percentage of bituminous matter than the Ohio shale, the amount sometimes reaching 24 per cent. It is a source of petroleum on a small scale, as is shown by the fact that in southern Ohio an important ledge of sandstone that belongs just above it is often found saturated with a tar-like oil, derived from this source.

11*d*. *The Cuyahoga Shale.*

It is impossible to retain for this great division of the Waverly the limits assigned to it by Newberry when he gave it its name. He made it fill the entire interval between the Berea grit and the Coal Measure conglomerate, and according to present knowledge, at least three distinct elements are to be found in every normal section of this interval. One of them has already been described, viz., the Berea shale, cut off from the foot of the column. Another, and a much more conspicuous element must be taken off from the top of the column, viz., the Logan group. But there still remain 150 to 400 feet of a perfectly distinct, homogeneous and most persistent formation that deserves a name as much as the Berea grit itself, or any other stratum in the Ohio scale, and for which no more suitable name could be found than that which it already bears, viz., Cuyahoga shale.

It consists of light-colored, argillaceous shales, which are often replaced with single courses of fine-grained sandstone, blue in color, and in southern Ohio weathering to a brownish-yellow. As a constant characteristic, there are found through the shales, flattened nodules of impure iron ore, concretionary in origin, and often having white calcareous centers.

By good rights the shale should suffer one more reduction at its

lower extremity. Everywhere through the state there is found directly above the Berea shale, or at a short remove from it, a number of courses of fine-grained stone. These courses are sometimes separated from each other by beds of shale, or they may be compacted into a single stratum. The individual courses also vary greatly in thickness, and in color and general characters. Throughout southern Ohio, and particularly in Ross, Pike and Scioto counties, the stratum yields freestone. It is best known from its outcrops on the Ohio river at Buena Vista, where it has long been very extensively worked for Cincinnati and other river markets. The Buena Vista stone, at its best, is one of the finest building stones of the country. The same horizon yields excellent stone near Portsmouth, Lucasville and Waverly. It is known as the Waverly brown stone at the latter point.

Northward, through the state, stone of more or less value is found in the bottom courses of the Cuyahoga, but in Trumbull county, near Warren, the horizon acquires extreme importance as the source of the finest natural flagging that is found in our markets.

It would have been well if the thirty or forty feet containing these courses had been cut off from the Cuyahoga shale, in which case the division thus formed would have been well named the Buena Vista stone, but inasmuch as the series does not absolutely require the change, it is left unmodified. As will be presently shown, the Sharpsville sandstone of White (Second Penna. Survey), belongs to this horizon, and is the proper equivalent of the Buena Vista stone.

There are a few sections in which the Cuyahoga shale is more largely replaced by these freestone layers than in the general account above given. In the cuts of the Marietta and Cincinnati Railroad, east from Chillicothe, the freestone appears to constitute a notable percentage, perhaps fifteen or twenty, of the whole material. There are other points at which the stone has no value.

Under cover the Cuyahoga shale retains with great distinctness and persistency the same characteristics that are found in its outcrops. From the deep drillings of eastern Ohio, wherever its horizon has been reached, there are uniformly reported 300 to 400 feet of white shales with occasional sandstone layers, through which the drill descends rapidly and easily. The Buena Vista courses are also frequently reported directly above, or at least near to, the Berea shale.

The fossils with which the Cuyahoga shale has been credited have been largely derived from the division next to be described, while this was counted a part of the shale. As here limited, it is, for most part, very poor in fossils. The surfaces of many of its beds are marked with

the impressions of the cock-tail fucoid, and in its upper portions occasional courses are found in which the animal fossils of this age are abundant and well-preserved.

11e. *The Logan Group.*

(The Olive Shales of Read. The Logan Sandstone of Andrews. The Waverly Conglomerate of Andrews).

The divisions of the Waverly series in northern Ohio happened to be made at a point where the section is abnormal and incomplete. By atrophy or by overlap, the upper member of the series is wanting in the Cuyahoga Valley, or is at least very inadequately represented there. The missing member is in volume second only to the Cuyahoga shale, among the divisions of the Waverly. It is much richer in the fossils of the Subcarboniferous than any of the other members. In composition it is varied and striking, one of its elements being a massive conglomerate not less than 200 feet in its largest sections, which extends in unbroken outcrop through at least a dozen counties of Ohio. No good reason can be found for dividing the Waverly series at all, if a member like this is to be left without a name, or is to be merged with an unlike and incongruous division from which it is as sharply differentiated as any one stratum of Ohio is from any other.

The real, though not the formal, separation of this group from the underlying shale, is due to the late Professor E. B. Andrews, and constitutes one of his most important contributions to our knowledge of Ohio geology. He was the first to show that the great conglomerate of Hocking, Fairfield and Licking counties is Subcarboniferous in age, and he further called attention to a highly fossiliferous, fine-grained sandstone overlying the conglomerate, to which he gave the name of Logan sandstone, from its occurrence at Logan, Hocking county. Up to this time this conglomerate had been universally counted as the Coal Measure conglomerate. Read made known the existence of a heavy body of shale, which he called Olive shales, overlying the conglomerate and replacing the Logan sandstone in Knox, Holmes and Richland counties.

As both conglomerate and sandstone have their typical outcrops at Logan, no better name can be found for the formation which must include conglomerate, sandstone, and shale, than that here adopted, viz., Logan group.

The maximum thickness of the Logan group is not less than 400 feet. Its average thickness is perhaps 200 feet. It has received less study than the rest of the series, and much work is needed in the

correlation of its several elements. The statements that follow may need revision in some particulars.

A typical or representative section of this group is scarcely possible, but the most characteristic and persistent part of the series is the conglomerate that is found at the bottom. At all events, coarse rock, if not always technically conglomerate, is generally found here. Pebbles do not make a conspicuous part of the rock when it takes a conglomeritic phase, in all cases. The most characteristic feature of the pebbles is their small and uniform size. The larger pebbles are generally flat. There is, however, a good deal of variation in all these respects.

Much of the conglomerate is fairly even in its bedding, and otherwise adapted to quarry purposes. The formation yields in central and southern Ohio quite a large amount of valuable stone.

The conglomerate is peculiar in this respect, viz., it is fossiliferous, containing both animal and vegetable fossils. The usual Subcarboniferous types of both divisions are found in it.

It is interrupted by layers of fine or medium-grained sandstone, and sometimes by shale deposits.

The prevailing colors are yellowish, red or brown. Much of it is handsomely variegated.

Its best developments are in Hocking, Fairfield, Ross, Vinton, Licking, Knox and Wayne counties, which constitute the northwestern arc of the sea-boundary of Ohio in Subcarboniferous time. South of Ross county it loses most of its pebbles, and south of the Ohio it becomes the knobstone of Kentucky. In northeastern Ohio the Logan group is also destitute of pebbles, and perhaps the conglomerate element proper does not appear here at all.

Professor I. C. White gives a generalized section of the rocks of Erie and Crawford counties, Pennsylvania, in Report Q. 4, page 66, of the recent Survey. He shows the presence of six sandstones in the scale, and three of these are common to the Ohio scale as well. The Shenango sandstone of his column is without doubt the representative of our Logan sandstone and Waverly conglomerate. His Sharpsville sandstone is our Buena Vista stone, and his Corry sandstone is none other than our persistent and important stratum, the Berea grit. The sandstones of the Pennsylvania column that underlie the Berea grit do not appear as such in the Ohio scale, as has been already shown. By the same token, White's Orangeville shale is the equivalent of our Berea shale, his Meadville shales are our Cuyahoga shale in part, and his Shenango shales are a part of our Logan series. While this view has long been held as to the more important elements, it is by means of sections recently made in Trumbull county, Ohio, by Mr. H. P. Cushing,

of Cleveland, that we are able to positively unite the Pennsylvania and Ohio sections in all of their essential elements.

Interstratified with the conglomerate courses in southern Ohio, are two or more fairly persistent layers of impure limestone. No fossils have been found in them. Similar layers occur in the Logan series of northeastern Ohio, except that in this case the limestones are fossiliferous. They are the Upper and Lower Meadville limestones of White, and can be followed into Ohio from Crawford county, Pennsylvania, where they were first described.

The Logan sandstone that succeeds the Waverly conglomerate in the full section is an uncertain and inconstant element, for the reason that it plays fast and loose with the stratum last described. Much could be said in favor of counting it the upper portion of the conglomerate. In its typical exposures, it is a fawn-colored, fine-grained, even-bedded sandstone. In this phase of the formation, the most favorable conditions for the marine life of the period seem to have been attained, the sandstone being prolific in fossils. The characters above given are quite widely held through the state. The Logan sandstone often rises to the base of the coal series.

The Olive shales of Read are probably the exact equivalent of the Logan sandstone in age. They seem to take its place in the central counties in part. Overlying the coarse rock in Knox and Coshocton counties, Read reports more than 300 feet of sparingly fossiliferous shales to which he gives the name here used.

Diverse as these elements are, they are blended and interlocked in the Logan group, leaving it in stratigraphy and fossils a well-defined and easily followed series throughout all parts of the territory in which it is due, except in possibly a small area in northern Ohio, as already noted, and even here, there is no difficulty in recognizing the pressure of this series. The several elements are, however, of smaller volume than elsewhere.

Under cover, throughout southeastern Ohio, the series is in the highest degree persistent and regular, much more uniform, indeed, than in its outcrops. It consists of 200 feet or more of prevailingly coarse rock, almost everywhere pebbly in spots, but interrupted with sheets of shale, yellowish and reddish colors being the characteristic ones. It has considerable interest in connection with gas, oil and salt-water in Ohio, being the reservoir of the brines of the Hocking and Muskingum Valleys, and furnishing in the latter large supplies of gas in the early days of salt manufacture in the state.

The Subcarboniferous series of Ohio has now, with the exception of a single element presently to be named, been passed in review. It is seen to be a very sharply characterized series, a most persistent sandstone, though not a thick one, lying near its base, bedded in shale and covered also by shale, the lower shale being often red in color and the roof shale being always black, and another sandstone or conglomerate stratum, 200 feet or more in thickness, forming the upper member of the series, these two persistent sandstones being separated from each other by 300 or more feet of light-colored, soft, argillaceous shales. No conditions could be more favorable for tracing such a group under ground than the conditions here found, and consequently the records of deep drillings in southern Ohio become almost as clear and legible as if the rocks, through which the drill has passed, lay exposed to the light of day.

12. The Subcarboniferous Limestone.

This element is of comparatively small account as a surface formation in Ohio, but it gathers strength to the southeastward of its outcrops, and is shown in many well records as a stratum fifty or more feet in thickness. It was recognized as a member of our geological column by the geologists of the first survey, but Andrews was the first to assign it to its proper place and to show its true equivalence. He named it the Maxville limestone, from a locality in southwestern Perry county, where it is well exposed in beds that aggregate fifteen feet in thickness. Still heavier deposits of it he found in the valley of Jonathan's Creek, in Muskingum county, near Newtonville. He collected its fossils by which its age was shown to be about that of the Chester limestone of the Missouri and Illinois sections.

The limestone, in its best development, is a fairly pure, very fine-grained, sparingly fossiliferous rock. It breaks with a conchoidal fracture. In fineness and homogenity of grain it approaches lithographic stone and has been tested in the small way for this special use. It is seldom even and regular in its bedding. Its color is light-drab or brown, and often it is a beautiful building stone, though somewhat expensive to work. The fire-clay found at this horizon in southern Ohio is one of the most valuable deposits of this sort in our entire scale. The limestone is found in outcrop in Scioto, Jackson, Hocking, Perry and Muskingum counties. It is reported in the well records of Steubenville, Brilliant, Macksburg, and at several other points in the Ohio Valley.

There remains to be briefly described, with reference to its gas and oil-producing properties, the great Carboniferous system of Ohio. An extended and careful review of its composition, as understood at the present time, is given in Geology of Ohio, volume V, and consequently it will be enough at this point to call to mind its more salient features. In the review in volume V, the Conglomerate series of Pennsylvania was included with the Lower Coal Measures, though the boundaries of each were shown to be clearly recognizable here. There are, however, less imperative grounds for the separation in Ohio than in Pennsylvania and the Virginias, and if only the Ohio series were to be classified, it is not probable that the divisions would have been made. But they stand for great and conspicuous facts elsewhere, and it probably would have been better to have maintained them in our territory also. The separation will be recognized in this review.

13. The Conglomerate Group.

This group consists of three great sandstones, between which and in which, are distributed two thin but persistent limestones and four coal seams of considerable value. The order is shown in the table below. A fifth coal seam is occasionally found:

Conglomerate Group.	Homewood Sandstone.	
	(Tionesta coal).	
	Upper Mercer Group.	Ore.
		Limestone.
		Coal.
	Lower Mercer Group.	Ore.
		Limestone.
		Coal.
	Massillon Sandstone, Upper.	
	(Quakertown Coal).	
	Massillon Sandstone, Lower.	
	Sharon coal—Coal No. 1, of Newberry.	
	Sharon Conglomerate.	

This group has an average aggregate thickness of 250 feet. At least, this figure need not mislead the student of our geology, though the range is great. It has some importance as a source of gas and oil in a few localities, as will hereafter appear.

14. The Lower Coal Measures.

This division includes for Ohio the most important section of the Coal Measures. In it are found six seams of coal, four horizons of limestone, including the most important of the coal measure limestones, viz., the Ferriferous, and several valuable iron ores and fire-clays. Its interest in the present connection is, however, chiefly confined to its sand-

stone ledges, four of which attain to fair development and extension. They are, in ascending order, the Hecla sandstone, immediately underlying the Ferriferous limestone, and mainly confined to the southwestern boundary of the coal field; the Kittanning sandstone, also mainly confined to the southwestern part of the coal field, and lying between the two Kittanning coals; the Lower Freeport sandstone, quite massive, and in a number of counties distinctly conglomeritic; the Upper Freeport sandstone, less massive and important in Ohio, but still a persistent deposit. Some of these sandstones probably take a small part in gas or oil production in a few fields.

15. The Lower Barren Measures.

No detailed account of this section, nor of Nos. 16 and 17, need be given here. There is but one sandstone in all of these divisions that is known to be important in connection with the subjects of the present chapter. This is the Mahoning sandstone, a massive and conglomerate ledge at the base of the Lower Barren Measures. It produces quite an amount of petroleum in several fields of Ohio, particularly from its upper division which is also known as the Buffalo sandstone.

18. The Glacial Drift.

Over the various bedded rocks of at least two-thirds of Ohio are spread in varying thickness the deposits of the Drift, the most characteristic and important of which is the Bowlder clay. This frequently contains in its lower portions large accumulations of vegetable matter, the remains of coniferous forests that occupied the country before the advent of the Drift, or at some interglacial stage of its duration. Peat bogs are sometimes found buried in like manner in or under the bowlder clay. Thus the latest of our geological formations, as well as the earliest, contains materials that can give rise to supplies of inflammable gas.

The geological scale of Ohio, in its relations to oil and gas production, has now been briefly reviewed, but geological structure is also a factor in this production, and a clear comprehension of the relation of Ohio geology to these new sources of light and fuel require, in addition to the account already given of the various strata that constitute our geological column, an equally concise statement of the leading facts in the structural geology of the state, that is, of the folds into which its strata are bent and the troughs into which they dip.

B. The Geological Structure of Ohio.

The geological structure of Ohio is as simple as that of almost any other 40,000 square miles of the earth's surface. All of its strata except a small portion of the Coal Measures, were deposited in the waters of an ancient arm of the sea, of which the present Gulf of Mexico is the dwarfed and diminished remnant and representative. Its most fossiliferous limestones, as the Corniferous, for example, stand for clear waters of tropical warmth. Its conglomerates and sandstones required strong currents for their transportation from distant shores. Its shales must have been deposited in seas of at least moderate depth, large areas of which, as well as all of the shores were covered with sargasso-like masses of sea-weed.

These strata seem to have been deposited on a fairly regular and level floor, and they have never been subjected to very great disturbance, that is, they have nowhere been raised into mountains nor depressed into deep valleys, but still they have been warped and disorted to some extent in the course of their long history.

In the southeastern quarter of the state are a few anticlinal arches, all of which, however, are very gentle and low, and none of which can be traced for many miles in the direction in which they extend. They involve all of the strata that belong in the district in which they are found. A modification of the arch resulting in a terrace-like arrangement of the strata, is one of the most important phases of the structure in this portion of the state. It will be treated at considerable length in subsequent pages. In southwestern Ohio, the structure is exceedingly simple and easily read, so far as now appears. The movements to which this section of the state have been subjected, are as small as is consistent with their ready recognition and measurement.

Less is known of the structure of northeastern Ohio, and especially of the lake counties from Cuyahoga county eastward, than of any other quarter of the state. This fact is due in part, possibly, to the want of recognizable horizons in those counties from which dip can be readily calculated. In the shale formation that prevails here, and which attains a thickness of a thousand feet or more, there are absolutely no marks known by which we can follow particular horizons from point to point without the aid of directly connected outcrops, such for example, as are found in the walls of a gorge. The upper and lower boundaries of the shale wherever they can be reached, give every needed opportunity for such measurements. The lower boundary is the Upper Helderberg limestone, and this has been used in all the sections in which it is available. It is known to have been reached at Elyria, Cleveland, Mas-

sillon, Akron, and at other points on the lake shore. Further back from the lake we obtain in the Berea grit an excellent horizon to follow in tracing the disposition of the strata. By means of it a very important flexure is brought to light, which will presently be described.

The surface of northwestern Ohio is much more nearly level than that of either of the sections already reviewed. It constitutes a great plain, which is covered, and often heavily covered with drift deposits that entirely obscure the underlying rock for scores and hundreds of square miles. Up to a recent date it was not known that the underlying rock failed to share the monotony of the surface, but the explorations of the last two years have revealed the surprising fact that the rocky floor of the "black swamp" of old time is characterized by far greater irregularity of structure and by far greater suddenness and steepness of dip than the strata of any other portion of Ohio. The entire floor of northwestern Ohio, including the lake counties, as far east as Lorain county, is seen to lie in a disturbed and uneasy condition. It is not uncommon to find the rocks descending at an angle of two to ten degrees, but the descent is not, as a rule, long continued, and all of these irregularities are subordinate to, and included in the main dip of the strata.

The structure of the state can best be studied by taking one-half of it at a time. The western, or older half, will be first considered. The dominant feature in the structure and physical history of Western Ohio, is the so-called Cincinnati anticlinal. A number of facts pertaining to this will now be given.

1. The Cincinnati Anticlinal.

As soon as the geology of the Mississippi Valley began to be studied, it became apparent that there had been in early time an extensive uplift of the older rocks in the central parts of Tennessee and Kentucky and in southwestern Ohio, which had exerted a profound influence on all the subsequent growth of the regions traversed by and adjacent thereto. This uplift has received several designations, but the name given to it by Newberry, viz., *The Cincinnati anticlinal*, will here be adopted, inasmuch as this geologist has furnished by far the most careful and connected account that has yet been given of it.

It is to be recognized, however, that this structural feature has in it little or nothing of the character of an anticlinal or arch, as these terms are commonly understood. There is no roof-shaped arrangement of the strata whatever, but they are spread out in a nearly level tract, 100

miles or more in breadth. The slopes within the tract are very light, and are quite uniform in direction, and the boundaries of the tract are well defined, as a rule.

The Trenton limestone, as has already been shown, makes the floor of western Ohio. By means of the deep drilling that is now in progress throughout this part of the state, we have obtained soundings to this limestone floor so extensive that we are already able to restore approximately its topography.

This underground disposition of the Trenton limestone becomes very significant in connection with the Cincinnati uplift. In fact, it *is* the Cincinnati uplift; and the study of the facts pertaining to it will be found to throw more light on this earliest and most important structural feature of the state than can be obtained from any and from all other sources. The supply of the necessary facts from southern Ohio is thus far quite meager, and the lines indicating the depth of the Trenton limestone through this portion of the state are based on a small number of points, and through considerable areas they are purely conjectural. There is a still greater dearth of facts from Indiana.* But in northwestern Ohio the boundaries are already fairly continuous, and we can be sure that the contour lines, now indicated, are final, so far as the leading facts of structure are concerned. They will doubtless be sharpened, and minor sinuosities in them will be revealed by future explorations, but the shapes of the main areas are certain to remain nearly as they are represented now. These contour lines are roughly indicated on the accompanying map. The areas of the state in which the Trenton limestone lies above sea-level are left unshaded. The approximate areas in which the Trenton limestone is found between sea-level and 250 feet below are indicated by the lightest tint upon the map. The third belt takes in the territory in which the Trenton limestone lies between 250 and 500 feet below tide. This is by far the most important of all the areas that are here distinguished. The remaining belts advance by descending steps of 250 feet each. The depths at which the Trenton limestone is reached at the towns in which drilling has been done appear in the following list. These figures can also be used in the interpretation of the map.

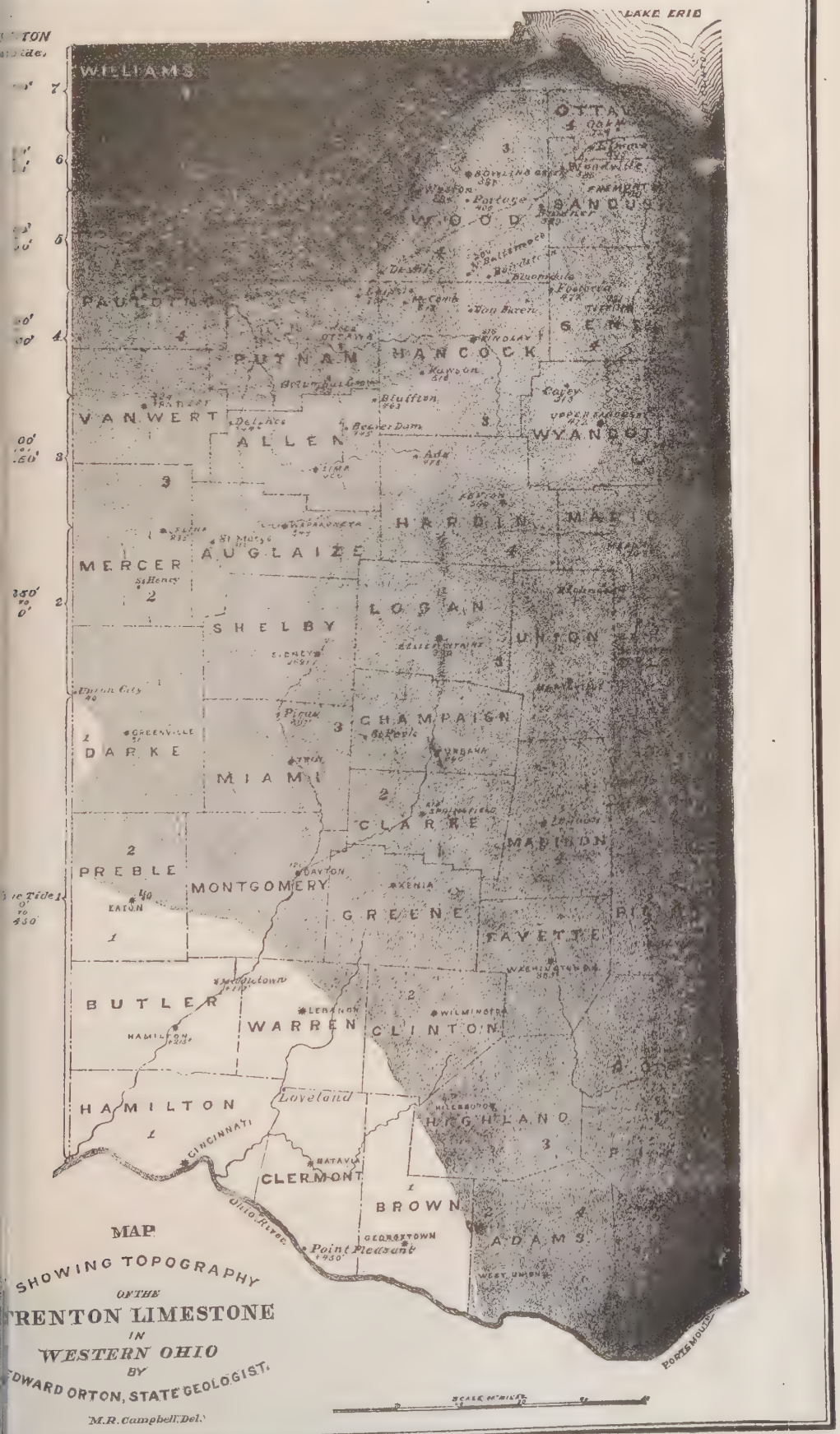
*Since the construction of the map a great number of additional facts have been obtained, but all of them fall within the lines already laid down.

The following list contains the elevation of the surface of the Trenton limestone with reference to sea-level, at a number of localities in western Ohio.

The list is made out in a geographical order, beginning in southern Ohio where the limestone has the highest elevation. Many of the figures given are approximate only, but they are close enough to give a true impression of the facts.

Where more than one well has been drilled, more than one set of figures obtains. Where great differences are found, the fact will be noted. In localities where scores of wells have been drilled, the figure given applies to the average of wells nearest the town.

Elevations of Trenton Limestone.	Above tide.	Below tide.
Allen county—		
Beaver Dam		445
Bluffton		463
Lima		381 to 401
Spencerville		330
West Newton		394
Auglaize county—		
Cridersville		370
St. Mary's		313
Wapakoneta		348
Butler county—		
Hamilton	70	
Oxford	70	
Champaign county—		
Mechanicsburg		400
Urbana		300
Clarke county—		
New Carlisle		200
Springfield		210
Clermont county—		
Point Pleasant	450	
Clinton county—		
New Vienna		96
Crawford county—		
Bucyrus		1,235
Crestline		1,680
Darke county—		
Ansonia		
Arcanum		100
Greenville		81
Union City		40
Defiance county—		
Defiance		975
Hicksville		962


LAKE ERIE
WILLIAMS
OTTAWA
SANDUSKY
WOOD
PAULDING
PUTNAM
HANCOCK
SENECA
VAN WERT
ALLEN
WYANDOT
HARDIN
MARION
MERCER
AUGLAIZE
LOGAN
SHELBY
UNION
DARKE
CHAMPAIGN
MIAMI
CLARKE
MADISON
PREBLE
MONTGOMERY
GREENE
FAYETTE
BUTLER
WARREN
CLINTON
HAMILTON
HIGHLAND
CLERMONT
BROWN
ADAMS
Dayton
Xenia
Eaton
Greenville
Piqua
Urbana
Springfield
London
Middletown
Lebanon
Wilmington
Washington
Loveland
Cincinnati
Batavia
Hillsboro
Georgetown
Point Pleasant
West Union
Ohio River
Bluffton
Bucyrus
Findlay
Fostoria
Tiffin
Lima
Ada
Kenton
Marysville
Delaware
Celina
St Marys
St Henry
Sidney
Piqua
Troy
Bellefontaine
Port Jefferson
Jamestown
Yellow Springs
Carey
Upper Sandusky
Fremont
Bowling Green
Portage
Bloomdale
Deshler
Van Buren
McComb
Ottawa
Brown
Beaver Dam
Defiance
Napoleon
Wauseon
Archbold
Stryker
Montpelier
Bryan
Edgerton
Hicksville
Antwerp
Paulding
Oakwood
Payne
Ney
Delphos
Wapakoneta
New Bremen
Minster
Fort Recovery
Greenville
Arcanum
Versailles
Tipp City
Covington
Troy
Piqua
Sidney
Anna
Russia
Jackson
Rushsylvania
Huntsville
Quincy
Zanesfield
Mechanicsburg
Urbana
St Paris
Catawba
Enon
Springfield
South Charleston
New Carlisle
Clifton
Yellow Springs
Fairfield
Middletown
Hamilton
Oxford
Lebanon
Franklin
Carlisle
Miamisburg
Centerville
Kettering
Dayton
Germantown
Eaton
New Paris
Camden
Lewisburg
Somerville
Oxford
Hamilton
Middletown
Monroe
Trenton
Carlisle
Franklin

ELEVATION OF TRENTON LIMESTONE—Continued.

Elevation of Trenton Limestone.	Above tide.	Below tide.
Erie county—		
Sandusky		1,629?
Fayette county—		
Washington C. H.		385
Franklin county—		
Columbus		1,188
Fulton county—		
Wauseon		1,367
Greene county—		
Osborn		165
Spring Valley		100
Xenia		114
Hamilton county—		
Cincinnati	150	
Hancock county—		
Arlington		430
Arcadia		370
Cannonsburg		443
Findlay		312 and 490
McComb		612
Rawson		516
Van Buren		330
Hardin county—		
Ada		478
Dunkirk		437
Forest		432
Kenton		560
Patterson		277
Henry county—		
Deshler		764
Napoleon		1,114
Highland county—		
Hillsborough		200?
Lawrence county—		
Ironton		2,750
Logan county—		
Bellefontaine		340
DeGraff		292
Huntsville		285
Lucas county—		
Toledo		812
Waterville		475
Madison county—		
London		550

ELEVATION OF TRENTON LIMESTONE—Continued.

Elevation of Trenton Limestone.	Above tide.	Below tide.
Marion county—		
Marion		707
Prospect		762
Mercer county—		
Celina		235
St. Henry's		200
Miami county—		
Piqua		307
Tippecanoe City		180
Troy		200
Montgomery county—		
Dayton		116
Ottawa county—		
Elmore		605
Genoa		663
Oak Harbor		724
Port Clinton		1,079
Preble county—		
Camden	Sea level.	
Eaton		40
Putnam county—		
Columbus Grove		526
Kalida		576
Leipsic		701
Ottawa		602
Richland county—		
Plymouth		1,910
Sandusky county—		
Clyde		1,070
Fremont		700 to 650
Seneca county—		
Fostoria		472
Tiffin		706 to 861
Shelby county—		
Sidney		269
Union county—		
Marysville		664
Magnetic Springs		650
Van Wert county—		
Delphos		447
Van Wert		434
Williams county—		
Bryan		1,200

ELEVATION OF TRENTON LIMESTONE—Concluded.

Elevation of Trenton Limestone.	Above tide.	Below tide.
Wood county—		
Bairdstown		301 315
Bloomdale		360
Bowling Green		387
Bradner		529
North Baltimore		380 451
Perrysburg		650
Portage		400
Weston		884
Wyandot county—		
Carey		513
Upper Sandusky		492

A study of the map reveals some unexpected results.

1. The Cincinnati uplift bears to the northwest, instead of to the northeast, so far as the highest lying regions of the Trenton limestone are concerned. The lines of strike or level bearing are approximately northwest lines. Starting from Point Pleasant, where the surface of the Trenton limestone is approximately 450 feet above tide, the line of slowest descent bears northwest through Clermont, Hamilton and Butler counties to Indiana. It apparently passes through the following counties of this last-named state: Union, Fayette, Wayne, Henry, Delaware, Madison and Grant. Connersville, Richmond, Winchester, Portland, Muncie, Eaton, Bluffton, Tipton, Kokomo, Decatur, Fort Wayne and Indianapolis, are places where drilling has been done, and where the depth of the Trenton limestone has been approximately determined. The figures used are given mainly on the authority of Dr. A. J. Phinney, of Muncie. They are as follows: Trenton limestone at Connersville, 127 feet above sea-level; at Richmond, 64 feet above sea-level; at Winchester, 24 feet above sea-level; at Muncie, 64 feet above sea-level; at Eaton, 5 feet above sea-level; at Portland, 71 feet below sea-level; at Bluffton, 215 feet below sea-level; at Decatur, 460 feet below sea-level; at Fort Wayne, 666 feet below sea-level; at Kokomo, 90 feet below; at Tipton, 129 feet below; at Indianapolis, 280 feet below. The following points show the line of highest elevations of the Trenton so far recognized: Point Pleasant, 450 feet above tide; Hamilton, 70 feet above tide; Eaton, Ohio, 40 feet below tide; Muncie, Indiana, 64 feet above tide; Eaton, Indiana, 5 feet above tide; Fairmount, 40 feet. below tide; Kokomo, 90 feet below tide. This line can be compared with lines drawn due north or northeast from Point Pleasant. A due

north line would show the following results: Point Pleasant, 450 feet below tide; Dayton, 116 feet below; Piqua, 309 below; Sidney, 267 feet below; Wapakoneta, 348 feet below; Lima, 400 feet below; Ottawa, 602 feet below; Napoleon, 1,114 feet below; Wauseon, 1,367 feet below. The facts in Indiana seem to indicate that the present western boundary of the Upper Silurian formation from Newcastle to Kokomo is determined by the uplift of the underlying rocks. We can put these facts into a full statement, thus: A long ridge of the Trenton limestone, extends from Point Pleasant into northern central Indiana, falling in this distance as it advances a little more than 500 feet and descending with some abruptness to the southwestward and northward at its extremity. If a similar line were to be followed from Point Pleasant an equal distance northward, as has been shown, its descent would be found to be nearly 2,000 feet, or four times as much as in a northwesterly direction. Or, if the line should be followed in the direction which has hitherto been supposed to be that of the Cincinnati axis to an equal distance, the descent would be found to be again nearly 2,000 feet, or four times as much as the descent of the line first named.

2. The line which marks the Trenton limestone at sea-level passes near Camden, Preble county, and about half-way between Middletown and Dayton, as we know. It is supposed to be continuous through the northeastern corner of Warren and the southeastern corners of Clinton, Highland, and Adams counties, respectively, to the Ohio river. The same boundary appears to return into the state once more, after having passed out of it to the westward. There is a small area on the west side of Darke county that is referred to this division. There is a far larger area of the Trenton limestone above sea-level in Indiana than in Ohio. This results from the state of things described in the preceding section.

3. The 250 feet boundary is established on a larger number of well established points than those that have already been named. Celina, St. Henry, Sidney, Piqua, Urbana, Springfield, and Washington Court House, are points in connection with those already named, which we have to guide us in drawing this line.

4. The next division, namely, that one that includes all the areas in which the Trenton limestone is found between 250 feet and 500 feet below tide, is not only the largest but by far the most interesting and important of the entire series. Its boundaries are established on a larger number of well records than any of the other lines that are laid down. The northern boundary crosses Van Wert and Allen counties in an easterly direction. It seems to bear due west in Indiana, passing between Decatur and Fort Wayne. In central Hancock county it turns

abruptly to the north, but as it advances it bears, at some points, a few degrees west of north. It follows to the Findlay break, and indeed is entirely based upon this important feature. It advances through Wood county almost to Lake Erie. Turning abruptly southward north of Bowling Green, it follows the devious line indicated to the Ohio Valley, but the location of the line in southern Ohio is largely conjectural. If Indiana and Ohio were connected on this map, we should see a much larger area of the Trenton limestone above the 500 feet level in the former state. The apparent easterly trend of the Cincinnati uplift, which appears in the surface limestone of northern and central Ohio is found to be due not to the flexure of the rocks, as was naturally supposed at first, but to a considerable thickening of the great shale series that underlies the Upper Silurian limestone. The Medina, Hudson River and Utica shales, which are counted together, reach twice as great a measure in the counties due south of Toledo, for example, as they have in the counties on the western boundary of the state.

5. Lines of steep descent are shown in the northwestern corner of the state, and also on the east side of the Hancock and Wood county neck; and again, especially rapid descents are found in Adams and Scioto counties. It is now seen that these steep descents are adequately indicated by the outcrops of the several geological formations, but until the testimony of the drill was in hand, we lacked the courage to draw these obvious conclusions. The thickness of the formation was also unknown, and without this element it was impossible to go far in this direction.

6. The early stages of the Cincinnati uplift in Ohio and Indiana are marked, as has been shown, by northwesterly trends, but a northeasterly formation afterwards appeared. It seems to have entered the state from Indiana as an offshoot of the main area of the high-lying Trenton limestone. It passes through the whole or parts of Darke, Mercer, Shelby, Auglaize, Allen, Hardin, Wyandot, Hancock and Wood counties. Its course is northeast from the Indiana line to Findlay, but at this point it turns due north, following a well-marked monocline, advancing thence to the Michigan line, which it reaches a little west of Sylvania. The northeasterly portion of this tract may be called the Lima axis, and the monocline may be named the Findlay break. The Lima axis is about thirty miles broad at its narrowest portion, counting the 500-foot line as its lower boundary, and the limestone lies very nearly level throughout this entire area. The Findlay break is abrupt and well marked, and is indeed the most remarkable fact in the structural geology of northern Ohio. The descent of the strata from east to west amounts to 150 or 175 feet, and this fall is generally accomplished

in less than half a mile. Frequently the strata descend at the rate of one foot in eight for 1,000 or 1,200 feet of horizontal distance. The break is equally well defined at Findlay, North Baltimore, Bowling Green, Monclova and Sylvania.

7. In front of this bifurcated axis in northwestern Ohio, and doubtless also in northeastern Indiana, there is a steep and rapid descent of the Trenton limestone as it takes its place under the Michigan coal field. The rocks appear to fall in a due north direction. A synclinal trough of the Trenton is revealed by the wells that have been drilled at Napoleon and Wauseon. The Trenton was found in the first at a depth of 1,114 feet blow tide, and in the second at a depth of 1,367 feet below tide. The latter figure was entirely unexpected, since at Toledo upon one side the level of the Trenton was found to be 800 feet below tide, and at Bryan upon the other side, 1,240 feet below, and no indication was apparent of any irregularity in the interval.

8. The contour lines in the northeastern section of the map follow meridians, as will be seen, that is, they are approximately north and south lines. Oak Harbor, Fremont, Tiffin and Marion all find the Trenton at nearly the same level, viz., 700 feet below tide. From these points southward a slight westerly trend of the contour line can be observed. In all the later stages of growth of those portions of the state that lie east of the line now traced, a prevalent and monotonous southeast dip is observed, the explanation of which must be found in a general elevation of the land to the west, at right angles to the dip, or in other words, in a northeasterly direction.

9. A greater significance is given to the facts obtained in Newberry's survey pertaining to the dip of the strata in southwestern Ohio, by these later explorations. In default of a better horizon, the Medina shale was adopted in 1870 as a base by means of which dip could be determined, and a number of interesting and important facts were brought out, the full meaning of which could not at that time be understood. The facts then obtained can be generalized as follows: (See Vol. I, page 415).

There is no apparent dip in the Cincinnati axis on an east and west line from the Indiana boundary as far as Springfield and Xenia.

Beyond that point the rocks descend at a fairly rapid rate.

The only appreciable dip in the Cincinnati axis is to the northward, and the rate in this direction is very small, varying between three and five feet to the mile.

2. The Normal Dip of the Strata.

The easterly or southeasterly dip of the rocks that begins at the margin of the tract now described as the Cincinnati axis, continues through the subsequent history of the state and constitutes the most important physical feature of its geology. All of the Subcarboniferous and Coal Measure strata, in particular, are affected by it. The southerly element of it gradually increases as we pass to northeastern Ohio, and it is probable that the dip becomes due south at some points in this portion of the state. Beyond the limits of Ohio, in Pennsylvania and West Virginia, the corresponding strata descend sharply toward the westward. These facts considered together, mark out the limits of the arm of the sea in which, and around which, the northern extension of the Appalachian coal field was built up, the Cincinnati axis forming its western boundary. These uniform and continuous southeasterly dips can be explained by the steady growth of the land to the westward, after the fashion already described. The dip is at right angles to the constantly advancing border of the sea. It seldom exceeds thirty feet to the mile, or but little more than half of one degree, in the large way, but it is alternately sharpened and reduced, so that for short distances a much greater fall or much less, may be found. The sections illustrative of the structural relations of our different strata bring these points into clear light.

The facts of our present topography seem to point to an original equality of elevation of those portions of the state that were successively brought under this uplifting force. The western outliers of all of the formations are, at the present time at least, at approximately the same elevation above the sea.

3. Other Arches and Folds.

The statements already made as to the exceeding regularity of the geological structure of Ohio need no qualification, but this regularity of the state, as a whole, is not inconsistent with the existence of a few minor folds and arches distributed, especially through the eastern half of our territory.

Beginning at Columbiana county on our eastern border, a low axis is found entering the state from western Pennsylvania. It crosses the Little Beaver a few miles above its mouth, near Fredericktown. It was first recognized by White, who named it the Fredericktown anticlinal. (Report on Lawrence county and the Ohio line, 2d Penna. Survey.) It is probably this axis that enters the Ohio Valley near East Liverpool, and that makes the conspicuous arch between that place and Wellsville.

Another slight fold is found along the line of the Cleveland and Pittsburgh Railroad. Its elevation is small and its extent has not been traced. The highest point of the arch on this line is near Salisbury. It may be called the Salisbury anticlinal. It was first noted by Newberry. (Geol. of Ohio, Vol. III, page 94.)

Below Steubenville for a few miles there is an arrest of normal dip, which has the effect and is, probably, the result of a low fold. The Wellsburg gas field is located in this region.

In the counties adjoining Columbiana and Jefferson, already referred to, no axes deserving the name have been thus far found. The search for them has not been thorough, it is true, but the two lines of railway that cross Belmont county, for example, have been examined for folds in the strata traversed by them, with negative results. The same thing is true of Harrison, on its southern side. Stevenson describes a small anticlinal passing through Cadiz. (Geol. of Ohio, Vol. III, page 201.) Throughout these districts, aside from the points named, the strata all seem to lie in their regular planes of slight and gradual descent to the east of south.

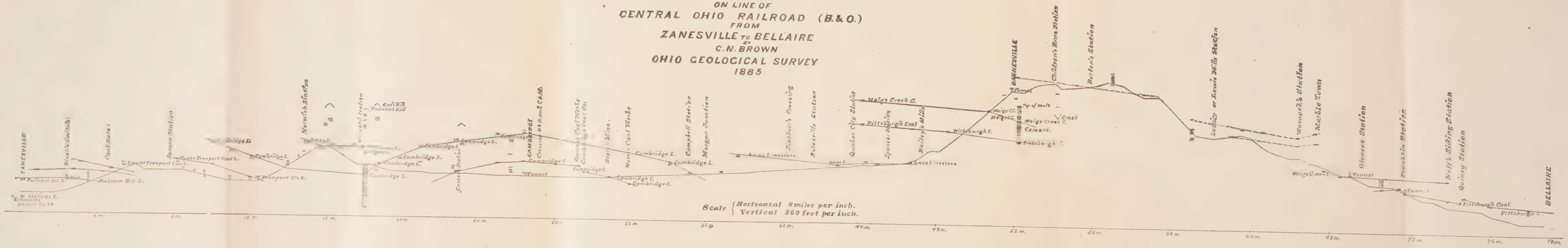
In order to test carefully these important facts of structure, a line of levels was run for the survey by Prof. C. N. Brown, from Zanesville to Bellaire, along the Baltimore and Ohio Railroad. The levels were connected at all available points with the geological elements that are due in this field. The results of this careful work are shown in the accompanying section. In it the Cambridge arch is the only distinct anticlinal that appears. There is a slight flattening of dip three miles east of Quaker City, and sundry hints of possible uplift or arrest of dip. The section shows, however, in striking terms, the extreme regularity of structure of eastern Ohio. Other examinations confirm this same view.

Further west and north, however, through portions of Stark, Tuscarawas, Guernsey and Muskingum counties, there is quite a broad and extended tract throughout which the normal dip of the strata is suspended or otherwise interfered with.

At least one well marked fold occurs in this field, the summit of which, on the line of the Baltimore and Ohio Railroad, is at or near Cambridge, and it can accordingly be named the Cambridge anticlinal. The belt of country above referred to lies within the margin of the coal field, and by the arrest of normal descent of the strata the coal seams of the Lower Measures are kept within easier reach than they would otherwise show.

The Cambridge anticlinal was first recognized by Stevenson. (Geology of Ohio, Vol. III, page 220.) He also reports a second fold in the same region.

GEOLOGICAL SECTION
ON LINE OF
CENTRAL OHIO RAILROAD (B.&O.)
FROM
ZANESVILLE TO BELLAIRE
BY
C. N. BROWN
OHIO GEOLOGICAL SURVEY
1885



It is probable that the Subcarboniferous series north and west of the region last described, has been affected by a similar movement. Facts that are coming to light in Knox, Coshocton, Holmes and other counties seem to point in this direction.

In Washington county several lines of moderate uplift have long been known. Special interest has centered in them as sources of petroleum. They are described in the chapter on the Macksburg Oil Field.

The difficulty of determining the dip in the shale series of northeastern Ohio has already been pointed out. It arises from the absence of easily recognized horizons in this formation. In the deep ravines and gorges by which the shales are traversed, opportunities are occasionally afforded to follow particular beds for a mile or two, and thus to note their flexures, but it is only when the Berea grit above the shales is reached, or when the drill strikes the Devonian limestone underneath them, that we acquire horizons clear and trustworthy enough to be used in large and connected calculations of the dip in which all the strata share. The Berea grit has been used as largely as possible for this service, and a considerable number of facts pertaining to the structure of the regions in which it is found are given in Chapter IV. In its outcrops in Lorain, Erie and Huron counties particularly, the local disturbances involving this formation are numerous and considerable. There are but few of the sandstone quarries in which steep dips are not found, the directions of which sometimes change in a single quarry. Adjacent quarries show the opposite sides of anticlinals in some instances. The facts have sometimes been explained as resulting from glacial agencies, but in all the sections in which the shales underlying the Berea grit are exposed to view, they are found to share fully in the flexures of the sandstone cover. It may well be that the sharply inclined portions of the Berea grit were best protected against denudation and glacial erosion, and that the frequency of quarries with steep slopes results from this fact. The larger undisturbed or less disturbed portions of the once universal formation have been swept away by the agencies of waste.

There is, however, a ridge of high-lying Berea sandstone that runs parallel to the shore of Lake Erie, though distant from it thirty or more miles, that demands a different explanation. All the sections involving the continuity of the Berea grit southward from the lake shore, display a low arch at this point, and when the elevations of the Berea grit are tabulated a line becomes apparent. At Mecca, the Berea grit is about 925 feet above tide at Akron, it is nearly the same elevation, viz., 910 to 930 feet; at Shelby, it is 945 feet, and at Plymouth about 990 feet. This line of facts has been noticed before, viz., in Vol. I, Geology of Ohio,

page 40, but the explanation there offered of the facts, viz., that the apparent uplift is due to the great thickening of the shale series to the southward, fails to cover the ground. The shale series expands from 800 feet at Elyria to 1,860 feet at Akron, as is elsewhere shown, but where the sandstone lies highest, at Shelby and Plymouth, the shales are but 650 feet thick, which is 150 or more feet less than at Elyria. The Berea grit at Plymouth is 300 feet higher than the same stratum at Elyria. The only explanation of the facts that appears adequate, is the obvious one that a low anticlinal extends from Shelby through Akron to Mecca, in a line about N. 70° E.

It is this Akron arch that constitutes the watershed of northern Ohio for at least a part of its extent. It also seems to provide a natural southern boundary for Lake Erie. The lake basin would, according to this view, be a synclinal.

It must be acknowledged, however, that we have not yet facts enough to fully establish the continuity of the fold that is here suggested. The points from which measurements are reported are so far apart that there is room between them for depressions in the stratum on which we rely. In accordance with such a view, Akron might lie on one low axis and Shelby on another.

The first explanation suggested is believed to be most consonant with all the facts in hand.

To sum up the statements now made, we know but comparatively few arches in Ohio, and these few are moderate in slope and small in height. Fuller knowledge of our geology will doubtless give us a larger number of these low folds, but there is little probability that any sharp and well defined anticlinals have altogether escaped notice. Those that remain to be discovered will agree with those already known, in breaking up the monotony of our series by the suspension or occasional reversal of the prevailing dip and in requiring close and accurate measurements for their detection.

By untrained observers, the watersheds of our drainage channels are often mistaken for anticlinals. If anticlinals traverse the series where these identifications are made, they may well serve to divide the drainage systems from each other, but such "divides" do not by any means require these structural accidents as the conditions on which they depend. Anticlinals must be demonstrated, not inferred.

The problems of our geology in this field are dependent on the use of the level. Accurate and connected series of elevations of well-settled horizons are indispensable to their solution. In the First Geological Survey of the state, Whittlesey recognized the need of physical determinations of the various elements of our coal fields in particular, and he

began at that time a valuable series of measurements, but his work was of necessity hampered by a want of well-determined geological horizons. The essential facts of identification of strata, without which the most careful measurements are futile, could only be secured by the prolonged study and the economical development of the field, the latter by means of the introduction of railway lines and the utilization of its minerals on a large scale.

This work of development has now been carried forward on both the scientific and the economic sides to such a point that definite solutions of many of the questions of our structural geology are easily attainable.

There are but few districts known in Ohio in which disturbances are to be found that fairly deserve the name of faults. In the northeast corner of Adams county and in adjacent territory, there are a number of square miles throughout which the strata are really dislocated. The Berea grit is found in contact with the Niagara shale in some instances. The throw of such faults must be at least 400 feet. Faults of this character in Ohio geology are as unusual and unexpected as trap dykes in northern Kentucky, the latter of which have been recently reported by Crandall (Ky. Geol. Survey).

In Geology of Ohio, Vol. V, page 262, mention was made of a small area of disturbance in the vicinity of Mineral Point, Tuscarawas county. No new facts have been gathered from this region. The Findlay monoclinal has been referred to already, and will be further described in a subsequent chapter.

The account of our structural geology, here given, seems called for in this connection by reason of the prominence that is given to anticlinals in the discussion and discovery of the recent natural gas supply of western Pennsylvania. The great wells upon which Pittsburgh depends are unquestionably located on the summits of pronounced folds. This fact has led to an eager inquiry in regard to similar folds in Ohio. The answer to such inquiries is that folds similar and equal to the great anticlinals of western Pennsylvania and West Virginia were never formed and consequently will never be found in Ohio. Our supply of this much-prized and eagerly-sought fuel, whatever it shall prove to be, must be independent of any conspicuous and easily-traced folds in our surface rocks.

CHAPTER II.

THE ORIGIN AND ACCUMULATION OF PETROLEUM AND NATURAL GAS.

By Edward Orton.

Natural gas and petroleum belong in a list of products of the crust of the earth to which we give the name of bitumens. Other bodies in the same list are the semi-fluid maltha and the solid asphaltum. All of these substances unquestionably have a similar, general history. They are found under the same conditions and the transitions from one to another, as of petroleum to asphalt, can be often noted. They are technically known as hydrocarbons, carbon and hydrogen constituting almost their entire substance, the former making about 85 per cent. and the latter about 13 per cent. of them.

They have long been known to man, and their use antedates history, but the importance which they now possess in the civilized world is of quite recent date. The discovery and use of petroleum on the large scale is included within the last twenty-five years, and all of the really important applications of natural gas belong to our own day, and are now in their initial stages.

Within the last fifty years, and particularly within the last twenty-five years, much has been written by geologists and chemists upon the origin and modes of accumulation of petroleum and gas.

Our knowledge as to the conditions of their occurrence in the rocks has been very greatly extended, and various theories have been advanced to account for the facts brought to light. There is no one theory that commands universal acceptance, and here, as elsewhere, it is no doubt true that theories are sometimes found opposed to each other because they respectively regard but one side of a subject which has more than one side.

Brief statements of the more commonly received views as to the origin and accumulation of these bituminous compounds will here be given. The statements are mainly derived from the excellent work of Prof. S. F. Peckham, on "Petroleum and its Products," contained in the 10th volume of the special reports of the United States Census Bureau

for 1880, to which the reader who desires fuller discussions of the subjects here treated must refer.

A. ORIGIN.

The theories as to the origin of petroleum and natural gas can be divided into two main groups, viz., (1) those which refer these bodies to inorganic sources, or in other words, which make them the result of chemical affinity acting on mineral matter, and (2) the theories that regard them as the result of a partial decomposition of vegetable or animal substances that have been stored up in the rocks.

These two classes of theories will be briefly considered.

I. Theories of Chemical Origin.

It has been claimed by a number of chemists, some of whom have high standing in the scientific world, that the several members of the series now under consideration can be referred to a purely mineral origin.

1. In 1866, the distinguished French chemist, Berthelot, propounded a theory that would, in his view, account for all of the natural hydrocarbons in this way. He supposed the alkali metals, viz., potassium and sodium, to exist in the interior of the earth in a free or uncombined state and, necessarily, at a high temperature. If, now, water carrying in solution carbonic acid—and the crust of the earth abounds in both—should find access to these metals, he pointed out the steps of the chemical action that must take place, and that would result in the formation of a series of hydrocarbon compounds. In this case, the process of oil and gas formation would be deep-seated and continuous, the reactions that give birth to them being constantly renewed in the recesses of the earth.

2. Another theory that invokes chemical force only for the origin of these bodies, was advanced by the eminent Russian chemist, Mendeljeff, in 1877. It attracted a large measure of attention and interest throughout the scientific world. He supposed the interior of the earth to contain large masses of metallic iron, and also metallic carbides (compounds of carbon and metals), all at a high temperature. The contact of water under these conditions with these bodies would, in his view, generate metallic oxides and hydrocarbons. Mendeljeff, accordingly, holds that petroleum is never of organic origin, but is as purely a product of chemical affinity as a veinstone, or an ore. It would follow from this theory, also, that the process of oil and gas formation is continuous.

There are several other theories of the same general character, but none that have been supported by as great authority, or that have attracted as wide attention as the two already named.

In regard to this class of theories, it is to be observed that they are the work of chemists and not of geologists, and, as might be expected, they match better with the chemical than with geological facts involved. They especially fail to account for the different sorts of oil and gas that characterize different rocks, as limestone and sandstone, for example. More important still, they fail to account for the distribution of petroleum and gas.

It is further to be observed that the hypotheses which they depend on, and which are indispensable to the theories, are of the sort that are doomed forever to remain hypotheses. They are, in their nature, incapable of verification. They cannot advance beyond their present stage, that of chemical and geological possibilities. There are fields of scientific speculation in which we have, and from the nature of the case, can have only such materials, but this is not true of the subjects now under consideration. In the fact that all of these theories "require the assumption of operations nowhere witnessed in nature or known in technology," we find enough to condemn them or, at least, enough to forbid any large measure of confidence in them.

II. Theories of Organic Origin.

The theories of the next class stand on a very different footing from those already named. According to them, petroleum and natural gas are derived from vegetable and animal matter contained in the rocks in which they are found or in associated strata. The argument for this view is simple and direct. Compounds, similar to or identical with petroleum and natural gas, are easily derived by the process of destructive distillation from both vegetable and animal substances, as from wood, peat, bones, oil, etc.

The manufacture of artificial gas from bituminous coal is also a familiar illustration of the possibilities in this direction. Bituminous shale may be substituted for coal in the manufacture, and may be made to yield a series of these bituminous products, including both petroleum and gas.

Further than this, the decay of vegetation, at ordinary temperatures, gives rise to light carburetted hydrogen or marsh gas, if the air is excluded from the decaying substance. These conditions are met when vegetable matter, as wood and leaves, is buried at the bottoms of ponds and lakes, or on a larger scale, in the beds of glacial drift. As is well known, large accumulations of ancient vegetation are buried in or

beneath the bowlder clay in many parts of the country, and these masses sometimes yield gas in large enough amount to be of economic value. Peat bogs not only yield inflammable gas, but sometimes produce other members of the bitumen series, nearly allied to petroleum and asphaltum, as has been shown by many competent observers, and among them the veteran English geologist, E. W. Binney, may be specially named. In a word, it is scarcely too much to say that in the natural or artificial decomposition of organic substances in the absence of air, both petroleum and gas are normal products. If this is so, and if in the rocks, both material and force are found that would produce these substances in the ordinary course of nature, why invent far-fetched and unverifiable theories to account for their presence?

While, therefore, the derivation of petroleum and gas, from vegetable or animal substances, is at present accepted by almost every one whose opinions on the subject are entitled to consideration, there is still a good deal of diversity of view as to the manner in which the work has gone forward. In fact the enquirer soon learns that beyond the general conclusion already noted, there is little agreement among our most responsible authorities as to the particular mode of origin of the substances under discussion. There is not only a want of positive knowledge upon the subject, but there is also a lack of self-consistent and thorough-going theory. Two views have become especially prominent in this country in the discussions of the last twenty years, and to the one or other of these, most of those persons who seek for well-balanced and presentable opinions on this line of questions, are found to subscribe.

The first view is, that petroleum is in large part derived from the *primary decomposition of organic matter* that was stored in, or associated with the strata that now contain it. According to this view, the decomposition was mainly effected *in situ*, and the product resulting is therefore mainly *indigenous* to the rock in which it is found. The last feature is seized upon in most popular statements, and a *theory of indigenous origin* is made to include most beliefs of this class. It must be borne in mind, however, that no author is to be found who holds strictly and consistently to such indigenous origin, but the name can still be used as a general designation without harm.

The second view is that petroleum is derived from the *secondary decomposition of organic matter* stored in the rocks. It supposes the original vegetable and animal matter to have suffered a partial transformation and to be now held in the rocks as hydrocarbon compounds, from which, *by a process of distillation*, oil and gas are derived. The so-called bituminous shales are counted the chief sources of these products. After distillation, it is held that the gas and oil are mainly carried upward by

hydrostatic pressure to some overlying porous stratum that serves as a reservoir. This class of views can be conveniently grouped under the name of the distillation theory.

A few words will be devoted to each of these theories.

1. *Theory of Origin from Primary Decomposition of Organic Matter.*

a. Statement of Hunt's Theory.

The most elaborate and effective exposition of the theory that petroleum is derived from the primary decomposition of organic tissue, is that of Dr. T. Sterry Hunt. He urges, with great force and vigor, the view that petroleum mainly originates in and is derived from limestones. When found in limestones he counts the oil indigenous, but when found elsewhere, as in sandstones and conglomerates, he counts it adventitious, and he then refers it to underlying limestones. In regard to this latter point, however, he makes concessions, as will be seen on a later page.

The following extracts from various articles that he has published, contain a clear statement of his views upon this subject.

In speaking of the oil fields of Canada, he says:

"The facts observed in this locality appear to show that the petroleum, or the substance which has given rise to it, was deposited in the bed in which it is now found at the formation of the rock. We may suppose in these oil-bearing beds an accumulation of organic matters, whose decomposition in the midst of a marine calcareous deposit, has resulted in their complete transformation into petroleum, which has found a lodgment in the cavities of the shells and corals immediately near. Its absence from the unfilled cells of corals in the adjacent and interstratified beds, forbids the idea of the introduction of the oil into these strata either by distillation or by infiltration. The same observations apply to the Trenton limestone, and if it shall be hereafter shown that the source of petroleum (as distinguished from asphalt) in other regions is to be found in marine fossiliferous limestones, a step will have been made toward a knowledge of the chemical conditions necessary to its formation."[1]

Again, he says:

"In opposition to the generally received view, which supposes the oil to originate from a slow destructive distillation of the black pyroschists, belonging to the middle and upper Devonian, I have maintained that it exists, ready formed, in the limestones below."[2]

This statement seems to recognize the possibility of the transfer of petroleum from its sources to reservoirs in associated strata.

Again, after describing the occurrence of petroleum in certain fossils and certain layers of the Corniferous limestone, he says:[3]

[1] A. J. S. (2), 35, 168.
[2] A. J. S. (2), 46, 361.
[3] A. J. S. (2), 35, 157.

"The facts observed in this locality appear to show that the petroleum, or the substance that has given rise to it, was deposited in the bed in which it is now found at the formation of the rock."

Finally, in referring to the bitumen-bearing dolomite in the Niagara series near Chicago, he says:

"With such sources ready formed in the earth's crust, it seems to me, to say the least, unphilosophical to search elsewhere for the origin of petroleum, and to suppose it to be derived by some unexplained process from rocks which are destitute of the substance." (Essays, p. 174.)

In this passage, also, a possible transfer of petroleum seems to be recognized.

These statements leave nothing to be desired as to clearness and explicitness. The author's view could not well be put into more concise terms than he has used. It must be added, however, that he has sometimes described the oil of Pennsylvania and Ohio as indigenous to the Devonian and Carboniferous sandstones which contain it. (Essays, p. 171.)

Professor J. P. Lesley has also urged the view that petroleum is derived, at least in some conspicuous instances, from vegetable remains that are still found associated with it in the rocks, but he does not theorize as to whether it results from primary or secondary decomposition. In a well-known paper on the petroleum of the eastern coal field of Kentucky, he refers this petroleum to the great conglomerate at the base of the Coal Measures. He says:

"A conglomerate age, or horizon of petroleum exists. This is the main point to be stated, and must be kept in view apart from all other ages or horizons of oil, whether later or earlier in order of geographical time. The rock itself is full of the remains of coal plants, from the decomposition of which the oil seems to have been made. . . . . For hundreds of square miles this vast stratum of ancient seasand is a thick packed herbarium of coal-measure plants. . . . . We can easily conceive of the wide, flat, sandy shores of the coal islands of the ancient archipelago of the coal era becoming completely charged with the decomposed and decomposable reliquiæ of both the plants of the land and the animals of the sea."

Professor Lesley has also advocated the indigenous origin of the Pennsylvania petroleums in many of his discussions of the subject, but some of his latest statements seem to show that he also considers petroleum and gas to have been gathered in the sandstones that now contain them, from some lower source.

Professor I. C. White has also supported the view that the petroleum of the third oil sand of Venango county, Pa., is indigenous to this rock, basing his belief on the abundance of vegetable remains that he

finds in the outcrop of this sandstone in Erie county, Pa. (See Report on Erie county, 2d Penna. Survey, page 239).

Professor J. D. Whitney has expressed the belief that all of the bituminous minerals of California, including asphalt and petroleum, are derived from the remains of infusoria in mineral limestones, but he has not expanded this view into any formal statement.

The opinions of several eminent American geologists have now been quoted in support of the general view that petroleum and gas originate in the strata in which they are found, and so far at least as the most extended statement is concerned, by the primary decomposition of organic matter.

The testimony of geologists from other parts of the world could also be adduced to support the above-named view, if it were counted necessary at this point. It is enough to say that the opinions of a number are on record which express in the clearest manner a belief in the primary derivation and thus in the indigenous origin of petroleum.

2. *Theory of Origin from Distillation.*

The second of the main theories previously noted, viz., that petroleum and gas are the product of the secondary rather than of the primary decomposition of organic substances, or in other words, that they are derived from the hydrocarbons of the rocks by a process of distillation, is accepted far more widely than the view previously named. In connection with this theory, it has always been held that these products of distillation are carried upwards by hydrostatic pressure to be stored in porous reservoirs or to escape at the surface. This doctrine has without doubt aided in giving currency to the distillation theory with which it has always been associated, but it must be observed that it is not incompatible with the first-named theory of the origin of petroleum, and that it has been of necessity recognized, at least by implication, by the advocates of the first theory. Whatever the origin of petroleum, it is certain that it has been accumulated by the method here indicated, at least in many instances. The distillation theory must therefore be considered by itself.

That petroleum and gas can be produced from coal, bituminous shales and other rocks by the process of destructive distillation, is known to all. The same products, we should have a right to expect, if similar rocks should be subjected to volcanic heat while buried deep below the surface.

When, therefore, we find these or other members of the bituminous group present in the rocks of volcanic districts, or in the neighborhood of hot springs or, in a word, in regions where elevated rock-temperatures

prevail or have recently prevailed, we refer them without hesitation to a process of distillation from the strata which the heat has traversed. Conditions are seen to be at hand similar to those which we establish in the artificial production of these substances. It may be added in passing that petroleum and asphalt are very frequently found under the circumstances named above.

Such an origin cannot, however, be made out for the great supplies of petroleum and gas in the eastern United States. These are, without exception, drawn from regions which have never been invaded by igneous rocks, and which have been but little disturbed by geological accidents, the uniform and monotonous dip of their formations being only occasionally interrupted by the low arches that traverse them.

b. Statement of Newberry's Distillation Theory.

The theory that has been most elaborately stated, and most widely accepted of all advanced to account for the oil and gas of the Alleghany field, is that of Newberry, who refers the origin of these substances to the extensive deposits of Devonian and Subcarboniferous shales, and particularly black shales, that underlie the productive districts. He considers petroleum and gas the products of a slow spontaneous distillation of the organic matter of the shales, and he regards the process of their formation a continuous one.

In his noted paper on the "Rock Oils of Ohio," published in the Ohio Agricultural Report for 1859, he says:

"The precise process by which petroleum is evolved from the carbonaceous matter contained in the rocks which furnish it is not yet fully known, because we cannot in ordinary circumstances inspect it. We may fairly infer, however, that it is a distillation, though generally performed at a low temperature."

Again he says (Geology of Ohio, Vol. I, p. 192):

"The origin of the two hydrocarbons (petroleum and gas) is the same, and they are evolved simultaneously by the spontaneous distillation of carbonaceous rocks."

In Vol. I, Geology of Ohio, p. 158, he says:

"I have already referred to the Huron shale as a probable source of the greater part of the petroleum obtained in this country. . . . . The considerations which have led me to adopt this view are briefly these:

"First. We have in the Huron shale a vast repository of solid hydro-carbonaceous matter which may be made to yield ten to twenty gallons of oil to the ton by artificial distillation. Like all other organic matter this is constantly undergoing spontaneous distillation, except where hermetically sealed deep under rock and water. This results in the formation of oil and gas, closely resembling those which we make artificially from the same substance, the manufactured differing from the natural products only because we cannot imitate accurately the process of nature.

"Second. A line of oil and gas springs marks the outcrop of the Huron shale from New York to Tennessee. The rock itself is frequently found saturated with petroleum, and the overlying strata, if porous, are sure to be more or less impregnated with it. . . . . Again, the emanations of oil and gas from the Lower Silurian rocks at Collingwood, Canada, and on the upper Cumberland River, Kentucky, are associated with similar deposits of black shale which represent the Utica slate of New York.

"Third. The wells on Oil Creek penetrate the strata immediately overlying the Huron shale, and the oil is obtained from the fissured and porous sheets of sandstone of the Portage and Chemung groups, which lie just above the Huron, and offer convenient reservoirs for the oil it furnishes."

So far, at least, as pointing out the sources of Pennsylvania oil and gas, this statement has met with wide acceptance among geologists.

Peckham says of the oils of Pennsylvania and adjacent territory:

"These oils are undoubtedly distillates and of vegetable origin. The proof of this statement seems overwhelming. Pennsylvania petroleum was examined in 1865 by Warren and Storer, in this country, and in 1863 by Pelouze and Cahours in France, who found the lighter portion to consist of a certain series of hydrocarbons, identical with those obtained in the destructive distillation of coal, bituminous shales and wood, when the operation was conducted at low temperatures."—Census Reports X, 69).

To most of those who have studied the subject with care, a statement even as positive and emphatic as this will seem in its main claim scarcely too strong. The vegetable matter to which Peckham refers the origin of Pennsylvania petroleum must be mainly the organic matter contained in the Devonian shales which underlie the productive regions, and presumably of vegetable origin.

Precisely what is meant by the term "spontaneous distillation," in Newberry's theory, it is not easy to determine, as his statements are not explicit in regard to all of the points in regard to which questions would arise. He does not seem to require, for oil production, any unusual temperature. He speaks of the distillation as "constant," and as going on "at a low temperature." He never uses the term "destructive distillation," and though he sometimes compares the production of natural gas to processes included under the head of destructive distillation, there are other passages in which he seems to make distillation cover the ordinary decomposition of organic matter in stations from which the air is mainly excluded. This is not, however, an authorized use of the word. Distillation, as distinguished from decomposition, requires and depends upon the action of temperatures decidedly above the normal, in other words, of high rather than of low temperatures. In fact, there is no process known under the name of distillation by which the substances under consideration could be produced from organic matter in the rocks, except destructive distillation. Those who

have criticised Newberry's theory have, in all instances, counted destructive distillation as involved.

c. Statement of Peckham's Distillation Theory.

There is, however, another statement of the distillation theory that must be briefly considered. It is that of Peckham. It is clear and self-consistent, recognizing all the necessary factors and conditions. He refers the oil and gas of Pennsylvania, and adjacent territory, to a distillation effected by the heat that accompanied the elevation of the Appalachian mountain system. He says (Census Reports X, 70):

"Bitumens are not the product of the high temperatures and violent action of volcanoes, but of the slow and gentle changes at low temperature, due to metamorphic action upon strata buried at immense depths. . . . . It is not necessary here to discuss the nature or origin of metamorphic action. It is sufficient for our purpose to know that from the Upper Silurian to the close of the Carboniferous periods, the currents of the primeval ocean were transporting sediments from northeast to southwest, sorting them into gravel, sand and clay, forming gravel bars and great sand-beds beneath the riffles, and clay-banks in still water, burying vast accumulations of sea-weeds and sea-animals far beneath the surface. The alteration, due to the combined action of heat, steam and pressure that involved the formations of the Appalachian system from Point Gaspe, in Canada, to Lookout Mountain, in Tennessee, involving the Carboniferous and earlier strata, distorting and folding them, and converting the coal into anthracite, and the clays into crystalline schists, along their eastern border, could not have ceased to act westward along an arbitrary line, but must have gradually died out farther and farther from the surface.

"The great beds of shale and limestone containing fucoids, animal remains and even indigenous petroleum, must have been invaded by this heat action to a greater or less degree. . . . . .

"Too little is known about petroleum at this time to enable any one to explain all the phenomena attending its occurrence on any hypothesis, but it seems to me that the different varieties of petroleum . . . . . are the products of fractional distillation, and one of the strongest proofs of this hypothesis is found in the large content of paraffine in the Bradford oil, under the enormous pressure to which it is subjected. . . . . .

"If this hypothesis . . . . . really represents the operations of nature, then we must seek the evidences of heat action at a depth far below the unaltered rocks in which the petroleum is now stored."

The statements now presented, inadequate and unfinished as they appear, are probably the most careful and extended that have been made upon the subject. They bring before us two main views as to the origin of petroleum, viz.:

(1) Petroleum is produced by the primary decomposition of organic matter, and mainly in the rocks that contained the organic matter. Of this view, Hunt is one of the chief advocates.

(2) Petroleum results from the distillation of organic hydrocarbons

contained in the rocks, and has generally been transferred to strata higher than those in which it was formed. Newberry and Peckham have been quoted at length in support of this general theory. Newberry holds that a slow and constant distillation is in progress at low temperatures. Peckham refers the distillation of the petroleum of the great American fields to the heat connected with the elevation and metamorphism of the Appalachian mountain system.

These three views as to the date of the origin of petroleum and gas are seen to cover almost all of the possibilities in regard to the subject. Hunt believes petroleum to have been produced at the time that the rocks that contain it were formed, once for all. Newberry believes it to have been in process of formation, slowly and constantly, since the strata were deposited. Peckham refers it to a definite but distant time in the past, but long subsequent to the formation of the petroliferous strata. He supposes it to have been stored in its subterranean reservoirs from that time to the present.

In these several statements as to origin, two questions are seen to be especially prominent, viz.: What particular kinds or classes of rocks are the sources of petroleum, and what is the nature of the chemical processes involved in its production?

In answering the first question, we find the views of Hunt and Newberry distinctly opposed to each other. Hunt counts limestones the principal source of petroleum, and denies that it has been produced by distillation from bituminous shales, while Newberry finds in these shales the main source of both oil and gas, and vigorously opposes the view that limestones are ever an important source of either. (Geol. of Ohio, I, 159.)

It is not necessary to follow the discussion in relation to these points further. It is enough to say that in the light of present knowledge each statement is right in its particular affirmations and wrong in its general denials. Petroleum is undoubtedly indigenous to, and derived from certain limestones, as Hunt has so strongly asserted. On the other hand, Newberry's doctrine that the great supplies of the Pennsylvania field are derived from Devonian shales, is becoming more firmly established and more generally accepted every year, though it seems likely that he has laid too much stress on *bituminous* shales.

In other words, the theories are not exclusive of each other. Different fields have different sources. We can accept, without inconsistency, the adventitious origin of the oil in Pennsylvania sandstones, and its indigenous origin in the shales of California, or in the limestones of Canada, Kentucky or Ohio.

The double origin of petroleum from both limestones and shales—and it is not necessary to exclude sandstones from the list of possible sources—deserves to be universally accepted. In confirmation of this double origin, it is coming to be recognized that the oil and gas derived from these two sources generally differ from each other in noticeable respects. The oil and gas derived from limestones contain larger proportions of sulphur and nitrogen than are found in the oil and gas of the shales. Nitrogen renders the oils unstable, and sulphur compounds impart to them a rank and persistent odor, from which they can be freed only with great difficulty. In the case of the oil-bearing shales of California, the petroleum is evidently derived from the animal remains with which the formation was originally filled. In composition this oil agrees with the limestone oils already described. It contains more than four times as much nitrogen as the Mecca oil of northeastern Ohio, and its percentage of sulphur is very high. Peckham says of these California oils:

"The exceedingly unstable character of these petroleums considered in connection with the amount of nitrogen that they contain, and the vast accumulation of animal remains in the strata from which they issue, together with the fact that the fresh oils soon become filled with the larvae of insects to such an extent that pools of petroleum become pools of maggots, all lend support to the theory that the oils are of animal origin." (Vol. X, p. 69).

He speaks again of this class of petroleums as formed of animal matter that has not been subjected to destructive distillation. (Ibid, p. 71).

It now appears as if oil and gas derived from animal remains can be distinguished from those of the bituminous shales by the characters above described. Certain it is that the "limestone oils" differ in physical characteristics from the Pennsylvania oils, for example, in a marked degree. They are dark in color; they are heavy oils, their gravity ranging generally from 34° to 36° Beaume, though sometimes rising to 40° or even 42°; they have a rank odor, arising from the sulphurous compounds which they contain. The oils of Canada, Kentucky, and Tennessee, and of the new field in northwestern Ohio, all agree in these respects, and the oil and gas of the Utica shale and Hudson River group of the state fall into the same category.

The organic matter of the bituminous shales has not been positively referred in the preceding statements to a vegetable source. Such a source is highly probable, but it cannot be said to be fully demonstrated until the origin of the so-called *sporangites* of the shales is finally determined. There are a few geologists who are inclined to refer these forms to hydroid zöophytes (animal) rather than with Dawson to marine

rhizocarps (vegetable). Whatever their origin, they give rise to petroleum and oil of a definite character, which is in marked contrast to that of the limestone oils.

Which of these theories, as to the mode and time of origin of petroleum, has the most to commend it?

d. Discussion of Peckham's Distillation Theory.

The statement under the second head, which refers it to destructive distillation of carbonaceous matter in the rocks, by the heat involved in the elevation of the Apalachian Mountain system, is the latest, and may well enough command our first attention.

This theory demands the agency of unusual temperature, and directs us "to seek the source of heat action far below the unaltered rocks in which the petroleum is now found."

How far below? If we descend 1,000 or 1,500 feet below the Berea grit, which is the great repository of oil and gas in eastern Ohio, we reach the bottom (on an average) of the Ohio shale, and this is the only source that we know in our series of oil and gas of the Pennsylvania type. But the drill has repeatedly gone down 1,000 or 1,500 feet below the Berea grit, and not a trace or hint of metamorphic action is found in the drillings that are brought up. In such drillings from the deep well at Canal Dover, 2,700 feet below the surface, and even 1,800 feet below the Berea grit, the microscopic spores that make so characteristic a feature of the black shales were found in normal condition. All observations attest not only the general uniformity of the shale formation throughout the state and at all depths, but also the entire absence of any appearance of metamorphic action.

The same line of facts obtains in regard to the limestones underneath the shales. They have been penetrated to a great depth. The drill in the well of the Cleveland rolling-mill rested at 3,200 feet below the surface, but the limestones at the bottom of the hole showed no signs whatever of metamorphism. The same is true of all the deep borings of northwestern Ohio. Nearly the whole of the Lower Silurian system has been penetrated there, and new supplies of oil and gas are found in these rocks, but they obviously come from the limestone themselves, and differ in a marked degree from the oil and gas of the shales. In Canada the Trenton limestone bears oil where it is separated by only a stratum of sandstone from the old granite floor of the continent.

But in the second place, Peckham demands for oil-production "slow and gentle changes at low temperature." We must again ask for a

limit. How low a temperature? Must it not be high enough to agree with the facts of observation and experiment as to the production of gas and oil by the destructive distillation of bituminous shales? The temperature at which such changes are effected in the laboratory will scarcely be placed below 400° Fahr. But the shales could not be brought to this degree without suffering metamorphic change. They contain alkaline solutions in greater or less amount, and both Bischof and Hunt have shown that when such compounds are present, they become powerful solvents of silica and silicates at as low a temperature as 212° Fahr. If, then, the temperature had been raised to even 212° Fahr., there would have been unmistakable evidences of the fact left in the constitution of the rocks.

But if a lower temperature is proposed than that which we are obliged to use in effecting destructive distillation in the laboratory, we are compelled to ask, on what authority? It is of no use to answer that we do not know at how low temperatures this distillation can be accomplished in nature. This is true, but it is none the less true that if we reason upon the subject at all, we must be governed by the facts that our experience affords. Any other way of reaching an answer is assumption, pure and simple.

In the third place, this theory would seem to necessitate a coke or carbonized residue in the rocks which give rise to the petroleum. Inability to point out such a residue seems to have been one of the reasons that led our author to locate the source of the oil-distilling heat at such great depth. He counts a carbon residue a necessity, but he buries the rock from which the petroleum is derived so deep that we cannot expect to obtain any direct knowledge of it. As has already been shown, in doing this, he drops below the only known source of oil and gas of the Pennsylvania type.

The absence of these residual products constitute a real difficulty in the way of any distillation theory.

On the whole, then, we are obliged to conclude that Peckham's theory does not harmonize with the facts of Ohio geology, and that it cannot be used to explain the origin of the substances whose history we are seeking to trace.

e. Discussion of Newberry's Distillation Theory.

The remaining exposition of the distillation theory has already been commented upon to some extent, on a previous page. As was there shown, its scope and meaning are not entirely clear. If it involves destructive distillation, as it seems to, the facts and arguments

already brought forward will apply to it without change. If it does not involve destructive distillation, then the theory requires to be restated and defined anew. Destructive distillation is the heating of organic substances beyond the point of decomposition without access of air. What "spontaneous distillation" is does not distinctly appear. If it can be shown that under the pressure of great depths, and with the normal increase of temperature due to descent, the transformations in question can go on, then a basis is supplied for this phase of the distillation theory, but so far as known, there are no facts whatever to warrant the belief that such a state of things is true. If, instead of distillation, this theory should substitute decomposition of organic tissues at ordinary temperatures without access of air, it would approach the theory of Hunt, that petroleum is due to the primary decomposition of organic matter.

f. Discussion of Hunt's Theory of Petroleum Formation.

There is something to be said in favor of Hunt's theory, that petroleum originates in the primary decomposition of organic substances, but his restriction of oil-production to limestones must, of course, be discarded, and just why the process should be made to terminate with the formation of the rock is not apparent. We know that vegetable substances may remain unchanged when buried in the earth for long periods, and so long as they are present in unchanged state, they would seem to be available for the process here appealed to.

Hunt denies that the so-called bituminous shales, "except in rare instances, contain any petroleum or other form of bitumen." (Essays, 169).

This statement is wide of the mark so far as the Ohio shale is concerned. It is to be regretted that quantitative examinations have not been made as to this point, but it is certainly true that either gas or oil or both are unmistakably present throughout our great shale series, and especially in the black bands that traverse it. Whether taken from the natural outcrops or from the deepest drillings, every fresh sample of the black shale attests by the characteristic odor the presence of these substances. In drilling through the shale along the shore of Lake Erie, in particular, the gas is generally found in some harder portion of the light-colored bands that compose so large a portion of the series, each harder cap or "shell" giving a new though short-lived supply, but the real source of the gas becomes apparent if the drill descends a little lower than the gas-producing "shell," when a darker band is almost invariably reported.

Newberry states the facts bearing upon this supply in the passage already quoted (p. ——), and Shaler sets the same line of facts in strong light in his discussion of the Ohio shale in Kentucky. (Vol. III, page 109, Geology of Kentucky.)

But the limestone series of Ohio is in very much the same case as the shale, so far as oil and gas are concerned. These substances are present in nearly all the limestone formations of the state, and apparently indigenous to them.

The Corniferous limestone, the first to be reached below the Ohio shale, in some of its fields and in certain courses, contains representatives of this class of substances. The Marblehead limestone, of Ottawa county, is classed by Hawes in the tenth Census reports (see Vol. X, page 80,) as a "bituminous dolomite." It gives out a bituminous order when struck with a hammer. But other portions of this limestone stratum are much more bituminous than the Marblehead stone.

The Waterlime or Lower Helderberg formation that comes next below, is decidedly bituminous. It contains grains of asphalt in cavities in the rock and carbonaceous films that have had the same origin, distributed through its substance. When struck with a hammer, it gives out the fetid odor of "limestone oil." Bowlders of it in the drift can be distinguished by this means from all associated limestones, except a part of the Corniferous. In Auglaize county, this stone becomes an asphaltic limestone, the bituminous element rising to a notable percentage. In other parts of the state, also, the amount of asphalt is so great that it is counted a decided advantage in the calcination of the stone for quicklime.

The Niagara limestone, as a whole, is less bituminous than the Helderberg, but there are parts of it, as in portions of Highland county, that contains a considerable amount of these products, mostly in the shape of asphaltic films and grains. Fossil corals are often partially occupied by this asphalt, and petroleum is sometimes found in small amounts.

The Clinton limestone is decidedly petroliferous in almost all of its outcrops. It yields oil in small amount at many points where quarries are opened in it, and springs that issue from it carry out small quantities of oil. These facts led, in the oil excitement of 1860, to the drilling of several deep wells along its line of outcrop. By the time the drill was buried in the rock this source of oil was passed, and the remainder of the descent was relieved by but little encouragement.

Small deposits of asphalt have been found under convex surfaces of the Dayton limestone, just above the Clinton stratum, the asphalt

being obviously derived from an inspissation of the oil of the latter formation.

The limestones of the Cincinnati group always contain bituminous matter in their outcrops, but when penetrated by the drill they have seldom yielded at any point large supplies of oil or gas. Short-lived flows have been, however, frequently reported from this series, both in northern and central Ohio.

The Trenton limestone, which has few outcrops in the state, but which underlies much, or perhaps all of its surface, has been proved, by means of explorations with the drill during the last year, to be frequently a source of oil and gas. In northwestern Ohio, it has given rise to an abundant supply of high-pressure gas at many localities, and also to oil wells, which have yielded as high as 5000 barrels of petroleum in a single day. The drill has penetrated at least 500 feet of this limestone series, and all portions of it have been found petroliferous, but the only great accumulations are found at and near the surface of the stratum.

The limestones and the shales of our geological series are thus seen to agree in these respects. Both of them carry petroleum through all of their substance, and the product of each class has its own characteristics. In other words, these supplies appear to be indigenous to the rocks of both groups.

Hunt's theory as to the petroleum in these limestones is, that it was formed in them at the time the beds themselves were formed, "by a peculiar transformation of vegetable matters, or in some cases of animal tissues analagous to them in composition." This is vague, it is true, and the stress is laid on the wrong element, probably, so far as the limestone oil is concerned, but why shall it not be extended for what it is worth to the other section of our rocks in which petroleum occurs under precisely similar conditions? If there is good reason for believing in the contemporaneous origin of oil and gas in the limestones, and if there is advantage to be derived from the doctrine as applied to them, the same reason will be found to exist in the case of the shales, and they should be allowed the same advantage.

The advantage that can, perhaps, be substantiated for this theory is, that in referring oil and gas to the primary and not to the secondary decomposition of organic matter, it rests upon processes which are known to be in present operation in the world.

One of the most important papers on petroleum formation is Wall's report on the Trinidad asphalt. A remarkable passage occurs in this report, which bears directly on the question before us. It is as follows, two sentences being here italicized:

"When *in situ*, it (the asphalt) is confined to particular strata which were originally shales containing a certain proportion of vegetable *debris*. *The organic matter has undergone a special mineralization, producing bituminous in place of ordinary anthraciferous substances. This operation is not attributable to heat nor to the nature of distillation, but is due to chemical reaction at the ordinary temperature and under the normal conditions of the climate.* The proofs that this is the true mode of the generation of the asphalt repose not only on the partial manner in which it is distributed in the strata, but also on numerous specimens of the vegetable matter in process of transformation and with the organic structure more or less obliterated. After the removal by solution of the bituminous material under the microscope, a remarkable alteration and corrosion of the vegetable cells becomes apparent, which is not presented in any other form of the mineralization of wood. . . . . Sometimes the emission is in the form of a dense, oily liquid from which the volatile elements gradually evaporate, leaving a solid residue." (Quart. Journ. Geol. Soc., XVI, 467.)

Wall's testimony is confirmed by other authorities. (See Hunt's Essays, 177.)

Petroleum, rapidly hardening into asphalt, is also recorded as occurring in some of the small tributaries of the Coaxocoalcas river in Central America. The petroleum seems to arise from the decomposition of vegetable remains with which certain beds of shale are stored. (Major J. G. Barnard's Survey of the Isthmus of Tehuantepec, 159.)

If Wall's statements are to be trusted—and they bear the marks of intelligent and discriminating observation, the facts are as follows:

Beds of shale, formed in comparatively recent times beneath the sea, but now raised above its level, containing in abundance vegetable remains brought down by the Orinoco river, near the mouth of which Trinidad is situated, are yielding petroleum in large amount, by a direct decomposition of vegetable tissues and the petroleum rapidly passes into asphalt, inasmuch as it is exposed directly to the atmosphere. There are some recent accounts, however, of the Trinidad asphalt which speak of a temperature of several hundred degrees C., being found in the center of the Pitch Lake.

At how great a depth in the rocks these changes are going on we have no observations to show, but no reason is apparent why these phenomena should be superficial. In subsiding areas, and almost all river deltas are such, the beds containing vegetable remains may be buried to a considerable depth before the decomposition can be fully effected, especially if the buried substances consist of the more durable vegetable products. In such a case we might expect the resulting petroleum to remain stored in the shale where it originated.

Why the phenomena of oil-production have been generally reported from shales, and not from sandstones, has not been explained. The difference between the two formations in this respect may be, in part, due to the fact that the shale seals up the vegetable matter more

perfectly than the sandstone. In the latter, ordinary decomposition would seem to have a better chance to go on.

Another fact to be noted in this connection, is the affinity of clay for oil of all sorts. Illustrations of this affinity are familiar to every one, but an observation of Professor Joseph Leidy's, made a number of years since, has special interest and value for us. He observed that on the bed of the Schuylkill river, for some distance below the Philadelphia gas works, a deposit of clay, impregnated with the petroleum-like oils that are produced in the manufacture of coal-gas, was in process of formation. These oily substances, which would otherwise be found on the surface of the river, are absorbed by the particles of fine clay in the water and gradually sink to the bottom with them, there forming a petroliferous clay on the river bed.

If petroleum, arising from such springs as occur in Central and South America, had found its way by rivers to lakes or seas, or had been liberated from sources beneath the sea, the same results would have followed. It would have been absorbed by the fine particles of clay held in suspension in river and sea, and the combined clay and oil would have been gradually carried downward to rest on the sea floor, an oil-bearing shale.

From the fact that all of the chief bituminous accumulations of recent age belong to the torrid zone, it seems necessary to conclude that a tropical climate, or a climate of 80° F., at least, is most favorable, if not essential to a large production of this class of bodies. The main asphalt deposits of commerce are found about the southern and western shores of the Gulf of Mexico.

The asphalt of Trinidad, which seems to be in constant process of formation, is derived from shales that belong to the later Tertiaries, and though derived from the most recent of all rocks that precede the present geological age, must still be separated from our time by a considerable interval. If then the formation of petroleum is made contemporaneous with the rock that contains it, it must be a geological contemporaneity that is meant, in which events that may be separated from each other by many thousands, or even tens of thousands of years, are counted contemporaneous.

But if petroleum is a result of the primary decomposition of vegetable tissue, so long as vegetable matter remains undecomposed in the rocks, and so long as the conditions of temperature and pressure remain favorable, what is there to hinder these processes of petroleum formation from going forward? Why limit it to the time of rock formation?

It would seem, however, that in the vast periods that have elapsed since the Paleozoic era, there would have been time enough and to spare for all of these changes to be accomplished, and that the process would be necessarily arrested, either for want of material or for lack of proper conditions.

The essential point in Hunt's theory of the origin of petroleum is, not that it was produced contemporaneously with the rock, nor that it is especially a product of limestones, but that it results from the primary decomposition of organic substances. Discarding these incidental elements of the theory, and applying its central postulate to the explanation of the origin of the petroleum of eastern Ohio and Pennsylvania, we can see what some of the steps in the history must have been.

The shales which constitute its chief source were accumulated in a tropical sea. The Devonian limestone which immediately preceded them in time bears witness to most genial conditions of climate. Its massive corals required at least as high an annual temperature as is found in any part of the Gulf of Mexico to-day.

The sedimentary deposits that were laid down on the floor of this Devonian sea consisted of clay and sand with occasional gravel bars, the sources of which must be sought in the rising Atlantic border or in the Canadian highlands, as is proved by all the deposits thickening and growing coarser in those directions. To the western limit of this sea, along the shores of the emerging Cincinnati axis, only fine clay was borne, and this fine and homogeneous material accumulated very slowly, one foot requiring as much time as ten or twelve feet of the coarser and more varied series to the eastward.

In these seas, as we know, there was a vast development of marine vegetation. Some plants of rhizocarpean affinities were especially abundant and their resinous spores and spore cases, which constituted by far the most durable portions of the plants, were set free in enormous quantities. Even now, in some parts of the series, these spores constitute a notable percentage of the shale. In structure and composition, they are but little changed from their original condition. Other portions of this and like vegetation may have been carried to the sea-floor in a macerated condition and have there passed through the coaly transformation, resulting in the structureless, carbonaceous matter that constantly characterizes the black shales. This carbonaceous substance can still be made to yield the members of the bitumen series through the agency of destructive distillation, and, doubtless, so also can the spores that remain unaltered in the shales, both leaving a carbon residue thereafter.

The shales that were slowly accumulating on the floor of this tropical gulf, thus charged with vegetable remains, must have behaved as similar shales do around the borders of the present gulf. The vegetable matter was turned into petroleum as it is in Trinidad and the West Indies now. The petroleum would have been absorbed by the particles of clay in contact with which it was originated, or, if liberated in the water, it would there have been laid hold of by the like floating particles of clay, to be carried with them in due time to the sea-floor, and the work would have gone on until the material was exhausted or the requisite conditions were lost.

The resulting stratum of bituminous shale would have been much more highly charged with petroleum than any portion of these shales is at the present time. Over it at last a bed of sandstone is deposited, which in turn is roofed in by another fine-grained shale. The pores of the sandstone are occupied by sea-water, but a slow system of exchanges would be established between the rocks by which, at last, the petroleum would be gathered into its final reservoir. The presence of petroleum in considerable amount in a shale might give it a measure of permeability.

Such would appear to be some of the steps in the production of petroleum, if Hunt's view of its origin by the primary decomposition of organic tissue is adopted. The result would correspond fairly well with those of the spontaneous distillation theory, already discussed. Both would find the petroleum distributed through the substance of the shales, and both would expect its constant escape from outcrops of producing shale or sandstone reservoir. Continuous origination is by no means a necessary conclusion from continuous outflow.

The advantage that the present theory has over others is, that it seems to find more support in the processes of nature at the present time. We find the bitumen series in actual process of formation in many parts of the world to-day, resulting apparently from the primary decomposition of organic matter, under normal conditions. On the other hand, we do *not* find this series, in any cases which are open to observation and subject to measurement, resulting from secondary decomposition of carbonaceous matter contained in the rocks, unless the comparatively high temperatures of destructive distillation are reached.

The several views as to the origin of petroleum that seem best to deserve attention have now been stated as fairly as possible. Some liberty has been taken with the last in the way of removing limitations,

but no new theory has been broached, and no real contribution to our knowledge of these very interesting questions is claimed. In subjects which tempt speculation as much as those which are now under discussion, it is well to know the opinions that are most entitled to respect, even where grounds of positive knowledge are wanting. How little real knowledge we have of this subject has been made to appear in this brief review, and it is safe to conclude that until the boundaries of our knowledge are considerably extended, every theory in regard to the origin of petroleum should be held as provisional only.

The theoretical views that we hold as to the origin of petroleum will influence our judgment also as to the duration of its supplies. The question is often asked, whether there is any provision in nature by which the supplies that are now drawn upon or exhausted, can be renewed. It is to be observed that of the several theories passed in review, only the discarded chemical hypotheses hold out any promise of a perennial supply. Of the three views from which most will feel obliged to make their choice, two answer the questions raised above emphatically in the negative, and the remaining theory gives in reality no more encouragement. Newberry's theory makes the process of oil formation a continuous one, it is true, but it extends it through such vast cycles of time that 1,000 years or 10,000 years would not constitute an important factor. In other words, the reservoirs that we are now piercing with the drill, and that are yielding such vast and valuable stores of light and power, would in all probability have yielded about the same supply 1,000 or 10,000 years ago.

Practically the stock is now complete, as much so as the contents of coal mines and mineral veins. As a result of our interference with natural conditions, small local movements of oil or gas may go on in the rocks, but these would be but insignificant exceptions to a general rule that the reservoirs hold all the oil and gas that they will ever hold, and that when once exhausted they will never be replenished.

Gas and oil have been considered together in all the preceding discussions, as if the history of one would cover the history of the other also. There are, however, speculations which dissociate them in origin. By some, gas is counted the first and original product, and it is supposed to be converted into petroleum in the sandstone reservoirs by some unknown process of condensation.

This question, like those that have preceded it, does not admit of a final and definite answer at the present time, but the chemical proba-

bilities do not seem to favor this view. Petroleum is more composite and unstable than gas, and in these respects it seems to stand at less remove from the organic world than the latter. A large percentage of natural gas is light carburetted hydrogen, one of the simplest and most stable products of decomposition. Petroleum readily gives rise to marsh gas when subjected to destructive agencies, but we have no known experience in which the higher compound results from synthesis of the lower. It seems, therefore, safe to count petroleum first in the order of nature.

A few words remain to be said under this head upon another subject. In the preceding discussions, shale and limestone have been considered the chief sources of petroleum, although, as is well known, sandstones are the direct source of the great supplies. There are some who hold that these supplies originate in the sandstones which now contain them. This view can be urged with plausibility, at least, for such sandstones as Lesley describes in eastern Kentucky or as White finds the LeBoeuf sandstone to be; but the Berea grit, which is the main oil sand of Ohio, is singularly free in most of its outcrops from all traces of vegetation. The claim at the best has many weak points, as is well shown by Carll (Penna. Geol. Survey, III, p. 272). Speaking of the Venango sands, he says:

> "We find that the largest wells are those which are sunk through the coarsest part of the oil-bearing sandrock. The drillings show nothing but coarse sand and pebbles. Pieces of the unpulverized rock, one or two cubic inches in bulk, are often brought up after torpedoing, but nothing can be detected in them that could possibly originate petroleum. Could a rock of this character have originally contained a quantity of organic matter sufficient to yield a cubic foot of oil to every ten or twelve cubic feet of rock, and these organic remains be so completely converted into oil as to leave no residual trace of their existence?"

With these questions and suggestions, and many others in the same line, he shows the difficulties of this view.

Summary.

In concluding this part of the discussion, a few of the previously stated propositions in regard to the origin of petroleum that seem best supported, will be repeated in concise terms:

1. Petroleum is derived from organic matter.
2. It is much more largely derived from vegetable than from animal substances.
2. Petroleum of the Pennsylvania type is derived from the organic matter of bituminous shales, and is of vegetable origin.

4. Petroleum of the Canada type is derived from limestones, and is probably of animal origin.

5. Petroleum has been produced at normal rock temperatures (in Ohio fields), and is not a product of destructive distillation of bituminous shales.

6. The stock of petroleum in the rocks is already practically complete.

B. MODES OF ACCUMULATION.

In the preceding pages, petroleum has been shown to be widely distributed in the rocks of Ohio. The limestones and shales of the series, in particular, everywhere contain it. Hunt has made a calculation, showing the amount of petroleum which the oil-bearing dolomite of Chicago holds to the square mile for every foot in thickness of the stratum. (Essays, p. 173.) If we apply a like calculation to the rocks of the Ohio scale, we shall find the total amount of oil enormously large. We may take, for example, the Waterlime stratum, which is notably and almost universally petroliferous. Estimating its petroleum content at one-tenth of one per cent., and the thickness of the stratum at 500 feet, both of which figures are probably within the limits, we find the petroleum contained in it to be more than 2,500,000 barrels to the square mile. The total production of the great oil field of Pennsylvania and New York, to January, 1885, is 261,000,000 barrels. It would require only three ordinary townships, or a little more than 100 square miles, to duplicate this enormous stock from the Waterlime alone. But if the rate of one-tenth of 1 per cent. should be maintained through a descent of 1,500 feet at any point in the State, each square mile would, in that case, yield 7,500,000 barrels, or nearly one-thirtieth of the total product of the entire oil field. These figures pass at once beyond clear comprehension, but they serve to give us some idea of the vast stock of petroleum contained in the earth's crust. If petroleum is generally distributed through a considerable series of rocks in *any* appreciable percentage, it is easy to see that the aggregate amount must be immense. Even $\frac{1}{1000}$ of 1 per cent. would yield 75,000 barrels to the square mile in a series of rocks 1,500 feet deep, but this amount is nearly one tenth of the greatest actual production per square mile of any of the leading Pennsylvania fields.

It is obvious that the total amount of petroleum in the rocks underlying the surface of Ohio is large beyond computation, but in its diffused and distributed state, it is entirely without value. It must be accumu-

lated in rocks that serve as reservoirs before it becomes of economic interest. In respect to the need of concentration it agrees with most other forms of mineral wealth.

I. Composition and Order of Sequence of Petroleum bearing Rocks.

a. Sandstones as Reservoirs.

The drillers in Venango county, Pennsylvania, in 1859, were not long in learning the facts as to the composition and order of arrangement of the series from which petroleum was obtained. Beginning in the valley of Oil Creek it was found that the drill first descended through several hundred feet of soft and fine-grained shales, after which a series of sandstones, imbedded in shale, was passed through.

These sandstones were three in number when the series was complete, and from the upper surface of the uppermost member to the bottom of the lowest, the interval was about 350 feet. It was at once learned that the petroleum, for which the drilling was undertaken, was confined to these sandstones, which, accordingly, took the name of "oil sands." They were named in order from above, the first, second and third oil sands. When all three were found in the well section, the oil was confined to the third or lowermost, but gas was sometimes found in the second, or even the first. When the third oil-sand was wanting, the second became the receptacle of the oil and gas, and when both the second and third were wanting, the stock was found in the first. The important fact thus came to light that the first sandstone to be reached in ascending order from the bottom of the series, was the oil-containing stratum. The rocks below the oil-sands were found at a somewhat later period to be gray or dark shales.

The Venango "oil-sands" proved to be sandstones of medium or coarse-grain, or even in some cases conglomerates. The third or lowermost sand, in particular, often assumed this phase, containing quartz pebbles in abundance. These sandstones were considered in the course of the development of the field, to be elongated bars of sand or pebbles, their longer axes extending in a northeasterly and southwesterly direction. The productive fields were found to extend in length for a score or more miles in some cases, while their width would be confined to one or two miles. In thickness, the oil-sands ranged from a shell to 100 feet. Some of them are described as having no outcrop, never rising to day in their own characters. Under the interpretation of the oil-sands given above, which is substantially that of Carll, these oil-containing reservoirs are seen to be lenticular in transverse section. It is in any

case certain that the productive belts showed the relations named above, and further, that production was related in a very definite way to the grain and thickness of the oil-sands. The coarser the sand and the more open, the greater the amount of oil, and in like manner the thicker the stratum, the larger was its production likely to be, other things being equal.

It must be noted, however, that all of the facts presented by such a field can be explained without supposing the oil rocks to be ancient sand-bars or submarine gravel ridges. Sandstone strata with an ordinary measure of continuity could present just such phenomena as we are called on to explain, under certain accidents of structure or arrangement. In fact, the sand-bar theory does not apply at all to the oil-production of Ohio. We find the oil and gas of eastern Ohio in a stratum of sandstone that rests on and that is covered by shales, but the stratum, so far from being lenticular in character, is wonderfully persistent, though varying in thickness and grain from point to point and occasionally nearly disappearing for short spaces.

It was also learned that the roof shales were not altogether impervious, but that through them oil, and especially gas, found their way upward, furnishing the so-called "surface indications." The thickness of the cover was found to be a factor in oil production to a certain extent, the larger accumulations seldom being found under light cover.

The first drillers in Venango county took possession of the valleys, counting the production of oil to be confined to them, but later comers began to try fortune on the slopes adjacent, and little by little the drilling rigs overran highlands as well as valleys, the fact being soon made apparent that the only necessary advantage possessed by the valleys was the shorter distance to be drilled to reach the oil-sand.

The wells drilled on the uplands revealed the presence of other sandstone strata, lying many hundred feet above the oil-sands. To these new strata the name of "mountain sands" was given, and three of these also were enumerated, viz., the first, second and third mountain sands. Petroleum and gas were sometimes found in these strata to a small extent.

The order that was thus ascertained to exist among the different strata penetrated by the drill in the valley of Oil Creek at the beginning of petroleum production, on the large scale, in this country, has proved to be the universal order, so far as the oil and gas fields of Pennsylvania, New York and eastern Ohio are concerned. In all of these fields, without important exception, sandstones buried in shales have proved to be the reservoirs of oil and gas when the latter are found in large quantity. The overlying shale is the cover or roof of the reservoir; the underlying

shale appears to be the source from which the bituminous products are derived. We can count on this as the established and essential order for oil and gas accumulation in the territory already named. Several distinct sets of oil-producing sands have been brought to light besides the Venango, the most important of which are the Warren and Bradford sands, both of which underlie the Venango system.

The three elements that constitute an oil-bearing group may exist by themselves, as in the Venango field, already described, or they may be buried under hundreds or even thousands of feet of superincumbent strata. In the latter case, several distinct oil and gas horizons may be traversed in a single well section, but each one will consist of the three elements named, cover, reservoir and source.

b. Limestones as Reservoirs.

In the less frequent cases where large accumulations of oil and gas are found in limestones instead of sandstones, the conditions vary somewhat from those just described. The shale cover is still an essential element, but reservoir and source of oil and gas are apparently blended in a common rock. The best examples of this sort of production are derived from the newly discovered fields of northwestern Ohio, where at a depth of 1,000 to 1,500 feet the Trenton limestone is struck. It is covered by 400 to 1,000 feet of shales, viz., the Utica, the Hudson River and the Medina shales, named in ascending order. The limestone itself has been penetrated for about 550 feet without being exhausted. Through most, if not all of its extent, it is petroliferous, as is shown by the drillings, but the accumulated stocks of both oil and gas are always found in the uppermost beds of the stratum, and generally not more than fifteen feet below its upper surface. Some fragments of the oil-bearing rock that have been brought out after the use of torpedoes in the wells, have been found to be quite porous, but other samples from wells of good production are fairly compact.

The oil rock carries, at a lower level than that in which the oil is found, but sometimes dangerously near, a brine of unusual character. It has, in fact, the composition of a bittern, or a water left over from the concentration of ordinary brine. It contains unusual quantities of chlorides of calcium and magnesium. It will be described more fully on a subsequent page of this report.

The facts as to the occurrence of the oil and gas in this stratum seem reconcileable with the theory that they have risen through the limestone rock until they find themselves arrested in their ascent by the overlying shales, and their accumulation therefore takes place at

this point. There is certainly nothing like bars or ridges in this oil-producing stratum, so far as its composition is concerned.

c. Permeability of the Reservoirs.

The fact that different portions of the oil-sands communicate with each other with more or less freedom, was early established in the history of oil-production in Pennsylvania. Adjacent wells were often found to affect each other's yield, and the locations of wells at once began to be made in consonance with this view. Wells were especially multiplied along boundary lines, under the selfish purpose of obtaining oil from the lands of others, and in the attempt to protect rights of ownership against such unjust invasions.

The descent of surface water into the oil-sands through abandoned wells proved disastrous to entire fields, and it became necessary to invoke stringent legislation to guard against this source of danger by requiring wells to be securely plugged before being abandoned. In these various ways it came to be seen that there was a fairly free communication through the oil-sands, at least in some cases, for intervals of one or more miles. So, also, in thick and gently-dipping strata like the Bradford oil-sand, the division of the rock into gas, oil and salt-water territories respectively, the gas holding the highest and the salt-water the lowest levels, made the conclusion well-nigh irresistible that the entire rock is permeable, and that, in the course of ages, its various contents have been differentiated as we now find them, under the influence of gravitation.

But on the other hand, it became equally clear that there was no necessary and absolute connection between different portions of an oil-sand, but that in many instances this stratum exists in lenticular masses, the several divisions of which may be nearly or even entirely disconnected. This conclusion is based on facts like these, viz., that contiguous wells often show no connection with each other, and that in what are supposed to be exhausted oil fields, small pockets of sand are sometimes subsequently discovered that furnish considerable supplies of oil. The rapid changes in thickness of the oil-sand in adjacent wells furnishes conclusive proof upon this point. We can follow the stratum down to a feather-edge by these records.

In oil-sands of moderate thickness, as the Berea grit, which ranges in Ohio between five and twenty-five feet through large areas, these interruptions more frequently occur. There are no facts known in Ohio which show a continuity in this stratum that allows the differentiation of its contents after the fashion and on the scale of the Bradford oil-

sand. Communication through a few square miles of the rock can be occasionally inferred, but beyond this we have, thus far, found no warrant for going.

We have fewer facts in regard to the limestone reservoirs, but it is easy to see that the same freedom of communication does not obtain here as in the sandstones that we have been considering. There cannot be, in the nature of things, as free communication through a massive limestone as through a sandstone of equal dimensions, where the latter has the open structure so often found in oil-fields. The gas-wells of Findlay, however, affect each other noticeably. The release of the gas in the famous Karg well has brought about an increase of oil production with a diminution of gas in several of the nearest wells.

An important factor in this discussion will be considered in the closing section of the present chapter.

d. Relative Importance of the Elements of an Oil-series.

Of the three elements already named as essential to oil production, viz., cover, reservoir and source, it is obvious that the last is the fundamental element, but inasmuch as the sources of petroleum in our rocks are so nearly universal, less importance attaches to it than to the other two. Furthermore, as rocks of various grain can be made to receive and retain these accumulations, more interest centers in the roof shales or cover than in any other part of the system. There can be no large accumulation without an approximately impervious roof. A considerable deposit of shale at any point in the geological series of the state is very likely, is, in fact, almost certain to cover an oil rock. For example, the great beds of shale just named cover the Trenton limestone, which is proved to be, at various points, a source of high-pressure gas and oil. The Niagara shale is, in many parts of the state, a moderately heavy deposit, and the Clinton limestone directly below it is very often notably petroliferous. The Ohio shale covers the Corniferous limestone, and though no large deposits of oil are known in this stratum in Ohio, we do not need to go far beyond our boundaries to find an important production from it, the Canada oil, of western Ontario, being referred to this horizon. The Cuyahoga shale makes the cover of the Berea grit, and this, as is well known, is the main oil and gas rock of all of eastern Ohio. Whenever the Logan conglomerate is roofed with shale, it, too, becomes petroliferous or gas-bearing. Numerous examples of oil and gas production from this horizon were furnished by the early salt-wells of the Muskingum Valley. Throughout the Coal Measures there are

not less than four sandstones roofed with shales that are found at times petroliferous.

From facts like these, it is apparent that the composition and order of arrangement of a series of strata have a vitally important relation to the accumulation of oil and gas that may take place within it. Some geologists count the composition of the series the main element in oil-production. They regard especially the grain and thickness of the oil-sand or reservoir, accounting largely for the difference in production of different fields, or of different parts of the same field by the character of the oil-sand. As already stated, the practical driller also makes great account of these facts.

Mr. John F. Carll, of the Second Pennsylvania Survey, has discussed these questions at length in his invaluable reports on the petroleum fields of western Pennsylvania. He claims that an oil-bearing pebble rock may contain, under favorable conditions, one-tenth, or even one-eighth of its bulk in oil, basing his claim upon the indications of experiments made upon the rock.—(Second Penna. Survey, I, 3, 251). He also shows that the pores of the sandstone would serve as channels for the largest supplies of oil that have yet been found, and that we are under no necessity of resorting to hypothetical "crevices" to account for any of the facts pertaining to the yield of oil-wells. Mr. Carll lays special stress upon the character of the oil-sand, and in this respect Professor Lesley and Mr. Ashburner seem to agree with him, while Professor I. C. White, also of the Second Pennsylvania Survey, urges the paramount importance of another element, especially in gas accumulation. This element will be next considered.

II. Effects of Disturbances of Strata Upon the Accumulation of Oil and Gas.

This subject is one which has been discussed ever since the discovery of petroleum and gas in this country on the large scale. Definite theories as to the influence of such disturbances as have occurred in the oil-producing territory were early propounded, some of which have been maintained to the present day. Prominent among them is the anticlinal theory, so-called, which takes account of the low arches or folds that have traversed some portions of the oil-producing districts, and especially of West Virginia and southern Ohio.

a. Earlier Statements of the Anticlinal Theory.

The "oil-break" of West Virginia, in the neighborhood of Burning Springs, furnished, in the early days of the search for petroleum, an

example of the effect of structural disturbance on oil production, that he who runs might read. There is an uplift there at once considerable and conspicuous, viz., the White Oak anticlinal, and the productive oil-wells, out of the great number of wells which were drilled in this region, were found to be strictly confined to the region of the anticlinal or axis. These facts were brought out in a very clear manner by the late Professor E. B. Andrews, in a paper published in the American Journal of Science (2, XLIII, 33). The discovery of the axis in its relation to oil-production seems to have been made by General A. J. Warner in connection with Professor Andrews, in 1865. Beyond the structural disturbance shown in the anticlinal, Professor Andrews also claimed the existence of crevices or fissures on the large scale in the rocks from which the oil was derived. To effect the separation of water, oil and gas in the supposed crevices, he invoked the force of gravitation, showing that these substances would necessarily be arranged in the order of their densities in any space which they should occupy in common.

The clue that was thus given as to the location of successful wells was, of course, promptly followed. The anticlinal was traced throughout its entire extent, and test-wells were put down at numerous points, but of these a large percentage failed. To account, if possible, for these failures, Mr. F. W. Minshall, of Parkersburg, West Virginia, undertook, at a later date, a careful determination of the levels of the axis. He found that, instead of either keeping a horizontal plane or of dripping regularly and uniformly, it advanced by a series of pronounced undulations, having domes or summits at some points, and sinks or sags at others. All of the productive oil and gas wells had been located on the domes, and the failures were to be found in the depressions. (10th Census Reports, X.)

Dr. T. S. Hunt, at a still earlier date, viz., in 1863, maintained that the petroleum supply of western Ontario was all derived from the line of a low and broad anticlinal, which runs through the district in a nearly east and west direction. He distinctly taught that the anticlinal structure is a necessary condition for a large production of petroleum, referring its accumulation in such portions of the series, of course, to hydrostatic laws. (Amer. Journ. of Science, March, 1863.)

Dr. Newberry seems also to accept the anticlinal theory, though his statements on this point are less explicit than those already quoted. In speaking of the Canada oil-field, he says:

"This district is in the line of the Cincinnati arch, which here, as in the islands of Lake Erie, shows evidence of disturbance long subsequent to its original upheaval."

In speaking of the Pennsylvania oil-fields, he says:

"These strata have all felt the disturbing influence of the forces which raised the Allegheny mountains Here, then, we have a peculiar geological substructure such as is especially favorable to the production and accumulation of petroleum, and such as must be, more or less, perfectly paralleled elsewhere to make productive or, at least, flowing wells possible. This structure consists in a great mass of carbonaceous strata below, more or less disturbed and loosened, from which the oil is supplied in a constant and relatively copious flow; above this, strata of porous, jointed sandstone, serving as reservoirs, where the constant product of oil and gas may accumulate for ages; still higher, argillaceous strata, impervious in their texture and not capable of being opened by fissures, forming a tight cover which prevents their escape." (Geol. of Ohio, I, 159.)

Elsewhere, he says:

"The facts I have observed lead me to conclude that the disturbed condition of the strata in certain districts east of Ohio, is the cause of the phenomena which they present. Where the oil and gas-producing rocks, and those overlying them are solid and compact, ... the escape of the resulting hydrocarbons is almost impossible. Where they are more or less shaken up, ... reservoirs are opened to receive the oil and gas, and fissures are produced which serve for their escape to the surface. Near the Alleghanies, all the rocky strata are more or less disturbed, and here, along certain lines, the liquid and gaseous hydrocarbons are evolved in enormous quantities. As we come westward, we find the rocks more undisturbed and the escape of oil and gas, through natural or artificial orifices, gradually diminished." (Ibid, 183.)

This reasoning, as will be seen, is in harmony with the anticlinal theory. From the statements already quoted, it is shown that distinct theories and claims have been advanced during the last twenty years, connecting the accumulation of oil and gas with anticlinal structure.

b. The Anticlinal Theory as Specially Applied to Gas Wells.

Within the last two years, since natural gas has attained such prominence in Pittsburgh, its sources and the conditions of its occurrence have been studied anew with sharpened inspection, by both geologists and practical men, and some real advance seems to have been made in our search for it. The anticlinal theory has been revived and extended, and has been used successfully in the location of many productive wells. For the new statement, we are indebted to Professor I. C. White, of the University of West Virginia, and recently of the Pennsylvania Geological Survey. Professor White, in turn, gives credit to Mr. W. A. Earseman, an oil operator of many years' experience, who had noticed in 1882–3, "that the principal gas wells then known in western Pennsylvania were situated close to where anticlinal axes were drawn on the geological maps. From this he inferred there must be some connection between the gas-wells and the anticlinals."

Professor White goes on to say:

"After visiting all the great gas-wells that had been struck in western Pennsylvania and West Virginia, and carefully examining the geological surroundings of each, I found that every one of them was situated either directly on or near the crown of an anticlinal axis, while wells that had been bored in the synclines on either side, furnished little or no gas, but in many cases large quantities of salt water. Further observation showed that the gas-wells were confined to a narrow belt, only one-fourth to one mile wide, along the crests of the anticlinal folds. These facts seem to connect gas territory unmistakably with the disturbance in the rocks caused by their upheaval into arches, but the crucial test was yet to be made in the actual location of good gas territory on this theory. During the last two years, I have submitted it to all manner of tests, both in locating and condemning gas-territory, and the general result has been to confirm the anticlinal theory beyond a reasonable doubt.

"But while we can state with confidence that all great gas-wells are found on the anticlinal axes, the converse of this is not true, viz., that great gas-wells may be found on all anticlinals. In a theory of this kind, the limitations become quite as important as, or even more so, than the theory itself; and hence, I have given considerable thought to this side of the question, having formulated them with three or four general rules, which include practically all the limitations known to me up to the present time, that should be placed on the statement that large gas-wells may be obtained on anticlinal folds, viz.:

"(*a*) The arch in the rocks must be one of considerable magnitude. (*b*) A coarse or porous sandstone of considerable thickness, or, if a fine-grained rock, one that would have extensive fissures and thus, in either case, rendered capable of acting as a reservoir for the gas, must underlie the surface at a depth of several hundred feet (500 to 2,500 feet). Probably very few or none of the grand arches along mountain ranges will be found holding gas in large quantity, since in such cases the disturbance of the stratification has been so profound that all the natural gas generated in the past would long ago have escaped into the air through fissures that traverse all the beds. Another limitation might possibly be added, which would confine the area where great gas flows may be obtained to those underlaid by a considerable thickness of bituminous shale.

"Very fair gas-wells may also be obtained for a considerable distance down the slope from the crest of the anticlinals, provided the dip be sufficiently rapid, and especially if it be irregular or interrupted with slight crumples. And even in regions where there are no marked anticlinals, if the dip be somewhat rapid and irregular, rather large gas-wells may occasionally be found, if all other conditions are favorable." (Science, June 26, 1885.)

To some of these statements, Mr. C. A. Ashburner, Geologist, in charge of the Second Pennsylvania Geological Survey, took exceptions, in a letter published in Science, July, 1885. He says:

"Professor White's theory that 'all great gas-wells are found on the anticlinal axes,' cannot be accepted, until he shall limit, by definition, all great gas-wells to exclude all gas-wells, both large and small, comparatively, which produce gas from strata not found either on anticlinal axes or in close proximity to such structural lines. The Kane gas-wells, the Ridgway well, the 'Old Mullin Snorter,' and several Bolivar wells are notable instances among many which might be mentioned, where large gas-wells have been drilled in or near the center of synclines.

"Although it is a fact that many of our largest Pennsylvania gas-wells are located near anticlinal axes, yet the position in which gas may be found, and the amount to be obtained, depend upon (a) the porosity and homogeneousness of the sandstone which serves as a reservoir to hold the gas, (b) the extent to which the strata above

or below the gas-sand are cracked; (c) the dip of the gas-sand and the position of the anticlines and synclines; (d) the relative positions of water, oil and gas, contained in the sand; and (e) the pressure under which gas exists before being tapped by wells."

To these criticisms Professor White makes reply, by urging that subordinate anticlinals often run along the central line of synclines, and that when gas is found in synclines it is at these points, and that when found here, it is seldom free from salt-water by which it is likely to be overpowered. He further urges that all the successful gas companies of western Pennsylvania and West Virginia are getting their gas from the crests of anticlinal axes, while those that have confined their operations to synclines, have met with uniform financial disaster. He points to the brilliant lights along the summits of the eight axes nearest to Pittsburgh, and he has since added a ninth, and also to the darkness that envelops the intervening synclines, in which hundreds of thousands of dollars have been invested without developing a single profitable gas-well.

To the qualifications already made, Professor White would probably add, at this time, one to the effect that gas-wells shall be located on the domes of the axis, rather than its depressions, recognizing the same line of facts in regard to them that Minshall had already established in the case of the White Oak anticlinal of Ohio and West Virginia, to which reference has previously been made.

The facts cited by Professor White as to the gas-supply of Pittsburgh, seem conclusive. Every foot of it comes from anticlinals, but not from them because it has been sought nowhere else, but because, if found in other stations it is speedily overcome and extinguished by salt-water. Where anticlinals of the type here referred to traverse an oil-bearing series, it may be considered demonstrated that they exert a decided effect on the accumulations of oil and gas in this series. So rational is such a conclusion, so directly does it result from the facts already stated, that it is hard to see on what grounds it can be called in question.

While there is no element of the theory, as stated by Professor White, that differs from the theory as heretofore stated, his applications of it are bold, original, and, best of all, successful, and they mark a new period in our study of the geology of oil and gas.

But as has been already shown, anticlinals are of infrequent occurrence in Ohio. A few of the low arches of western Pennsylvania extend across the border, but they soon flatten out and disappear. Even if anticlinals are held to account for the facts of oil and gas accumulation, the theory would have but limited application to our geology.

c. Arrested Anticlinals.

Though distinct arches are for the most part wanting in our geology, there is another sort of structural deformation found here, which is connected in a direct way with the oil and gas of eastern Ohio. The structure referred to is associated with the arrest or suppression of the prevailing dip of the rocks for a given space and the establishment of a terrace or level bench in its place. If the series had lain level instead of being inclined at the slight angle which marks most of eastern Ohio, the movement to which the present terrace is due would have resulted in a low arch, but the uplifting force was too feeble to do more than counteract for a short space the normal dip by which the entire series is affected.

The structure referred to comes out to view in the Macksburg oil field, and is represented in the maps and sections that accompany the report upon this field.

The entire series that is found to be connected here with oil production is at least 1,500 feet thick. It enters the field dipping gently to the southeast, at the rate of twenty to thirty feet to the mile, but it suddenly ceases its descent, and for about three miles there is no appreciable fall. In other words, a normal descent of sixty to seventy-five feet is neutralized. The amount of territory included in the terrace appears to be fifteen to twenty square miles. Beyond this, the regular dip is resumed.

In the 1,500 feet of rock which compose the section that the wells here penetrate, there are not less than five distinct oil-sands, or in other words, five horizons at which oil and gas are sometimes found. Each one of these is productive of oil to a greater or less degree, upon the terrace, and of gas, upon the upper margin of the terrace. The development of the field began with the discovery of oil in the shallowest sand. Step by step the lower horizons were reached. The productive areas of each have the same surface boundaries. The petroleum contained in the different sandstones has different characters, varying in gravity, in color, in chemical properties, from sand to sand. Wells are in operation in most if not in all of these horizons in the Macksburg field at the present time.

How are these facts to be explained? If there were an anticlinal fold here, it could be urged that the gas had found its way through the fractures and fissures of the arch from the bottom upward, so that one supply could account for charging all of the rocks. This explanation would leave the differences in quality of the oils found in the several rocks unexplained, it is true, but it might still be maintained. There

is, however, neither arch nor fold of any sort. That five sand-rocks distributed through 1,500 feet of stratified deposits, should each happen to secure the right grain and composition to make them repositories of oil, within exactly the same geographical limits, is of course incredible.

There is but one explanation of the facts here given. The accumulation of oil and gas is due to the structure, the arrangement, of the rocks concerned. In other words, structure is a vital element in the accumulation of oil and gas. The facts in eastern Ohio point to the conclusion that all other conditions for oil-production are met much oftener than the structural conditions required. The source of gas on the large scale is found in the universal sheet of shale that underlies this portion of the state. A reservoir is furnished by the Berea grit, almost as wide as this universal source of gas. The Cuyahoga shale has everywhere the essential conditions for roof or cover of the oil-sand. But all of these are powerless to produce an oil field until the right inclination is given to the series. This condition is met in but few instances, so far as our present knowledge is concerned.

The Wellsburg gas field in the Ohio Valley below Steubenville has a structure similar to the Macksburg field. There is a similar arrest of normal dip and a consequent terrace-like bench upon the summit of which the gas is found. Oil has not yet been reported from this field, but if explorations are continued it will undoubtedly be found.

Accurate measurements have not yet been applied to all of the few oil fields and gas fields of eastern Ohio, but so far as examination has gone every one of them betrays structural irregularity, and most of them point to the terrace-like structure already described.

The true character of the Macksburg field was first suspected and approximately determined by Mr. F. W. Minshall, but no instrumental measurements, other than barometrical, were employed until those that are recorded in a subsequent chapter of this report. By connecting the levels of the coals and limestones of the outcrop with the positions of the several oil-sands, as shown in the drill-holes, it is seen that the entire series has risen and fallen together, and that conclusions as to the depth of the lowest stratum reached, can be safely grounded on the elevation of those that are shown in the hill-sides.

d. Structural Irregularities in Northwestern Ohio.

The occurrence of petroleum and gas, but especially of the latter, in northwestern Ohio, has been found to be associated with greater irregularities of structure than are known elsewhere in the state, except in a single locality. The drift deposits of this region are so thick and so continuous that there are no adequate opportunities to determine the

horizons or dip of the underlying rocks by natural outcrops, and inasmuch as the surface does not betray any notable irregularity, it has been a great surprise to find, from the well-records, that the strata are dipping at some points at the rate of 300 feet to the mile. It is in Findlay that the most marked disturbance occurs, and the great supplies of gas that are found there appear to be closely connected with this disturbance. The largest gas-well is located near the edge of a steep descent, while others that are situated on the slopes yield both gas and oil. The wells at the bottom of the slope have yielded thus far oil alone, or oil and salt-water. The facts connected with this irregularity of structure will be fully stated in a succeeding chapter.

It is only necessary to state, at this point, that the gas of western Ohio, like that of the eastern half of the state, seems to depend upon unusual facts of structure for all of its important accumulations.

C. ROCK-PRESSURE OF GAS.

In connection with the modes of accumulation of gas in its rock reservoirs that have been already discussed, we come upon another topic of considerable scientific and practical interest, viz., the pressure exerted by the gas upon the rock in which it is contained. The only means that we have of ascertaining this pressure is by drilling into the gas-rock. The pipe that connects this reservoir with the surface will, when closed, contain gas in the same state of tension that exists in the rock. The pressure is determined by a steam-guage attached to the pipe. It is known as the rock-pressure or closed pressure of the well, and it ranges in amount from one to one thousand pounds to the square inch. In all the great gas-fields that are in process of exploitation, the rock-pressure ranges from 300 to 750 pounds, and beyond the latter figure it very seldom rises. In shale gas-wells the pressure seldom rises to 100 pounds, the ordinary range being between twenty-five and seventy-five pounds.

The open pressure of a well, on the other hand, is the pressure exerted by the column of gas escaping with unobstructed flow from the well. It is registered by a guage of some sort that is held in the current. The amount of open pressure depends upon two factors, viz., the volume of gas discharged in a given time, and the size of the orifice through which it is discharged.

The first element is not under our control, but by varying the size of the pipe, we find very different results. The smallest figure are, of course, obtained when the gas is escaping through the casing, or the 5⅝-inch pipe with which wells are commonly supplied. It requires a

fairly vigorous well to give one pound open pressure in a pipe of this size. The largest well ever struck in Ohio, viz., the Van Buren well of Hancock county, gave six pounds open pressure. When the same well was brought down to a 4-inch pipe, the gauge showed an open pressure of 20½ pounds.

Wells of less than one million feet per day will produce either no effect or too small an effect to be easily noted on a high-pressure gauge, and for such wells other means of measurement, as the water or mercury column or the anemometor, must be adopted.

In defining open pressure, a partial explanation of it has been at the same time given. It results from the volume of gas that escapes in a given interval from the reservoir, and thus obviously depends on the general conditions and especially on the porosity of the reservoir. It is not connected with, or dependent on the closed pressure of the wells. A well may have a high closed pressure and a very low open pressure. Such a well will require a longer time to reach its maximum after being locked in. The gauge shows a very slow rate of advance. The gas, in other words, comes into the well slowly, which is the same as saying that the well is a small one.

It is the open pressure by which the flow of a well can be determined. Nothing whatever can be told of the production of a well by its closed pressure, taken by itself. Wells in any field are quite likely to hold the same closed pressure, no matter what their production may be. That is, when locked in, all such wells will reach the same figure on the gauge. One well reaches it instantaneously, or in a very short interval. In another, the pressure creeps slowly up for hours, but at last it gets to the same point that its great neighbor reached in a minute.

If the element of time be combined with the element of closed pressure, an approximation can be made to the production of a well. It is obvious that a well that gains 100, 200 or 300 pounds in a minute has a much larger production than a well that gains 5, 10 or 20 pounds in the same interval.

It is probable that an empirical relation can be established for facts of this character, but no tables are yet known that cover the ground. The only scientific system of measuring the flow of gas-wells, that is at the same time applicable to wells of all grades of production, is that which will be found in a subsequent chapter of this volume. It is based on the open pressure of the gas, and by means of it the strongest well that ever blew can be determined by a simple and single measurement that can be executed in a few seconds at most.

Both the closed and open pressure of wells have now been defined,

and the latter has been explained to a certain extent. Can an explanation be offered for the facts of closed pressure as well?

The subject is an interesting and important one, but it is confessedly obscure and difficult. There has been but little written upon it by those whose judgment would be worth most to us. The facts pertaining to the closed pressure of great gas-wells are among the most striking in the whole range of mining enterprise. To be appreciated, a high-pressure gas-well must be seen and heard. The gas issues from it with a velocity twice as great as that of a bullet when it leaves a rifle. Sets of drilling-tools, nearly 100 feet long, and weighing 2,000 pounds, are lifted out of a well 1,000 or 1,500 feet deep and thrown high into the air. The noise with which the gas escapes is literally deafening, exposure to it often resulting in partial loss of hearing on the part of those engaged about the well.

What is it that originates this indescribable force? Three answers have been offered, but no one of them, so far as is known, has been expanded into anything like an elaborate and balanced statement. They have been thrown out as suggestions rather than as full-fledged theories.

One answer is, that the rock-pressure is derived from the expansive nature of the gas. Solid or liquid materials in the reservoir are supposed to be converted into gas as water is converted into steam. The resulting gas occupies many times more space than the bodies from which it was derived, and in seeking to obtain this space it exerts the pressure which we note.

This view has, no doubt, elements of truth in it, even though it fails to furnish a full explanation. For the pressure of shale-gas, it may be that no other force is required. But the theory is incapable of verification, and we are not able to advance a great ways beyond the statement of it. Some objections to it will also appear in connection with facts that are presently to be stated.

The second explanation that is offered is, without doubt, more generally accepted than any other by those who have begun to think upon the question at all.

This theory is to the effect that the weight of the superincumbent rocks is the cause of the high pressure of gas in the reservoirs. In other words, the term *rock-pressure* is considered to be descriptive of a cause as well as of a fact. That a column of rock, 1,000 or 1,500 feet deep has great weight, is obvious. It is assumed that this weight, whatever it is, is available in driving accumulations of gas out of rocks that contain them, whenever communication is opened between the deeply-buried reservoir and the surface.

Is this assumption valid? Can the weight of the overlying rock work in this way?

Not unless there is freedom of motion on the part of the constituents of the rock, or, in other words, unless the rock has lost its cohesion and is in a crushed state. If the rock retains its solidity, it can exert no more pressure on the gas that is held in the spaces between its grains than the walls of a cavern would exert on a stream of water flowing through it. Professor Lesley has discussed this theory with more elaboration and detail than any other geologist, and has shown its entirely untenable character. (Annual Report Penna. Survey, 1885.)

The claim that the Berea grit or the Trenton limestone, where they are, respectively, oil or gas-rocks, exists in a crushed or comminuted state, is negatived by every fact that we can obtain that bears upon the subject. The claim is a preposterous one, but without this condition the theory fails.

The third theory advanced to account for the rock pressure of gas stands on a different basis from those already named. It appeals to water pressure in the oil and gas-rock, as the cause of the flow of both these substances, and in this reference, it directs us to principles and facts of familiar experience and every-day use. Every one is acquainted with the phenomena and explanation of artesian wells. By this theory gas and oil-wells are made artesian in their flow. In the porous rock that contains them there is always, outside of the productive fields, a body of water, and in almost every instance, salt-water. This water occupies the rock as it rises to day in its nearest outcrops. Communicating there with surface water or with rainfall, a head of pressure is given to the gas and oil that are held in the traps formed by the anticlinals or terraces into which the stratum has been thrown. The amount of pressure would thus depend on the height to which the water column is raised, in case continuous porosity of the stratum can be assumed. Defects in regard to porosity would abate from the total pressure on the oil or gas.

This, in short, is the third and last of the explanations offered of the rock-pressure of natural gas. There seems little reason to doubt that it is along this line that the true explanation is to be found, though it is too early to claim that a full account can now be given of all the facts involved.

One of the significant elements in the case is the salt-water that surrounds every oil and gas-field. When the drill descends into this outside territory, salt-water promptly rises in the well to the surface, or to a given depth below the surface. Sometimes, indeed, it overflows. Why does the salt-water rise?

What other cause can be suggested than pressure from behind? The rise must be artesian. But just beyond the salt-water, on a slightly higher level of the rock, lies the oil pool. When that is reached by the drill, the oil flows out from the well. Will not the same cause that we found in active and unmistakable operation in the adjacent salt-water territory explain the flow of the oil from the second well? Is not this also artesian?

In like manner, the pressure of the gas that is confined within the highest levels of the same porous rock can be explained, and thus one familiar cause that is demonstrably present in the field is made to account for the varied phenomena presented.

With the exhaustion of a gas-field or oil-field, these substances are followed up and replaced by salt-water. This is the common fate of gas and oil-wells, the death to which they all seem to be appointed.

Certain obvious inferences follow the acceptance of this explanation:

1. The supplies of gas and oil are seen to be definitely limited by this theory of rock pressure. If a salt-water column is the propelling force, it is idle to speculate on constantly renewed supplies. The water advances as the gas or oil is withdrawn, and the closing stage of the oil-rock is, as already pointed out, a salt-water rock.

2. Other things being equal, the rock pressure will be greatest in the deepest wells. The deeper the well, the longer the water column.

3. Other things being equal, the rock-pressure will be greatest in districts the gas or oil-rock of which rises highest above the sea in its outcrops. The 750 lbs. of rock-pressure in Pennsylvania gas-wells, as contrasted with the 400 lbs. pressure of Findlay wells, can be accounted for on this principle.

4. The rock-pressure of gas may be continued with unabated force until the end of production is at hand. Maintenance of pressure is no proof of renewal of supply. The last thousand feet will come out of a gasholder with as much force as the first thousand feet.

5. Where both oil and gas are found in a single field, the first sign of approaching failure will be the invasion of the gas-rock by oil, or of the oil-rock by salt-water.

CHAPTER III.

THE TRENTON LIMESTONE AS A SOURCE OF OIL AND GAS IN OHIO.

By Edward Orton.

The entire history of the discovery and exploitation of petroleum in this country has been full of surprises, both to the practical men engaged in the work and to the geologists who have studied the facts as they have been brought to light, but no previous chapter of the history has proved as strange and well-nigh incredible as the discovery and development which are now to be described.

No fact in this line could be more unexpected than that any notable supplies of petroleum or gas should be furnished by the Trenton limestone, which is widely known as a massive, compact and fossiliferous limstone of Lower Silurian age and of wide extent, constituting in fact one of the great foundations of the continent. But when required to believe that certain phases of this Trenton limestone make one of the great oil-rocks of our geological scale, one which produces from single wells 5,000 barrels of oil, or 15,000,000 cubic feet of inflammable gas in a day, it is hard to prevent our surprise from passing into incredulity. It is this remarkable history which is to occupy the present chapter.

A brief account has already been given of the Trenton limestone (page 4, etc.), and its character, extent and composition have been indicated. To these statements, a few others are to be added.

The formation ranges in thickness from 50 to 800 feet, and when the limestone is replaced in part by shales, the formation sometimes becomes 2,000 feet thick.

In New York it is divided into two divisions, viz., the Trenton limestone proper, and the Black River limestone. The lower portion of the latter is sometimes separated from the stratum under the name of the Birdseye limestone. This designation is derived from the occurrence of small crystalline points in the limestone. Both of these divisions belong to the true limestones as distinguished from magnesian limestone.

In Illinois and Wisconsin, there is, also, a two-fold division of the formation, but on a different basis from that adopted at the east. The

divisions here recognized are called the Galena and the Trenton limestone. They are, respectively, 250 and 100 feet thick in maximum measurements. The upper, or Galena division, is, in its best state, a light-colored blue or drab, coarse-grained, porous, and almost pure dolomite. The underlying Trenton is, also, generally magnesian in composition, but it does not quite reach dolomitic proportions. It is also less pure in the main than the best phases of the Galena. (Geol. of Wisc., Vol. I.)

In central Kentucky, again, a twofold division of the Trenton is recognized, the two members being known as the Trenton and Birdseye divisions. The former is reported to be 175 feet in thickness, and the latter 130 feet. (Rocks of Central Kentucky, W. M. Linney, Ky. Geol. Survey, 1882.) In composition, the Trenton of Kentucky is impure, and contains but a small percentage (five to ten) of carbonate of magnesia, so far as can be judged from the few analyses available.

In Ohio, the Trenton limestone appears to agree in its divisions with those of Wisconsin on one side and with those of Kentucky on the other. In other words, it has a threefold division when all the deposits of this age in the state with which we have become acquainted are taken into account. In southern Ohio, the Kentucky series appears in the well sections, consisting of the Trenton proper and the underlying Birdseye. In northwestern Ohio, we find in the new oil and gas-rock, a stratum which is, so far as composition goes, the equivalent of the Galena dolomite, underneath which, rocks having the composition of the Trenton and Birdseye of the south appear.

The position of the Galena limestone in the geological scale, it must be added, is not entirely settled. A question has, at least, been raised in regard to it. Mr. C. D. Walcott, of the United States Geological Survey, has urged the view that instead of belonging to the Trenton epoch, it is really the equivalent and representative of the Utica shale, no trace of which in its characteristic form is found in the Wisconsin section. The absence of the shale proper is, in fact, one of the strongest arguments brought forward for the new reference. If the oil-rock of Ohio represents the Galena dolomite, then the argument above-named loses its force, because over this formation there is found the full section of the Utica shale, normal in every particular. If it does not represent the Galena division, it still exhibits as marked a departure from the ordinary character of the Trenton limestone as the latter does, and thus weakens the argument for separating the Galena.

A number of analyses of the several members of the Trenton group will here be given, illustrative of the differences in composition that

have been already referred to. The uppermost, or dolomite division, will be represented first:

1. Galena limestone, Wisconsin.—*Bode.*
2. Findlay gas-rock, Ohio.—*Lord.*
3. Lima oil-rock, " "
4. Bowling Green gas-rock, Ohio.—*Lord.*
5. Kokomo gas-rock, Indiana.—*Lord.*
6. Upper beds of Trenton limestone, Escanaba river, Michigan.—*Geol. Survey.*
7. " " " " Whitefish " " "

	1	2	3	4	5	6	7
Carbonate of lime	54.05	53.50	55.90	51.78	52.80	51.00	52.00
Carbonate of magnesia	44.14	43.05	38.85	36.80	39.50	38.00	38.50
Insoluble residue	1.57	1.70	.75	4.89	4.60	7.00	5.50
Ox'e of iron and alumina	.25	1.25	2.94	.....	2.40	2.50	3.00
	100.01	99.50	98.44	.....	99.30	98.50	99.00

The next group of analyses represents the composition of a lower division of the Trenton series, which is counted the Trenton limestone proper in a considerable part of the country. Under this head the Trenton of New York and New Jersey will find a place. No sharp line can be drawn between this and the succeeding group:

No. 1—Drillings 100 feet below gas-rock, Bowling Green, Ohio.—*Lord.*
No. 2— " 50 feet below surface of Trenton, Springfield, Ohio.—*Lord.*
No. 3—Middle division, Trenton limestone, Escanaba river, Mich.—*Geol. Surv.* I, 78.
No. 4— " " " " Whitefish " " " " "
No. 5— " " " " Bristol, Wisconsin.—*Daniells.*

	1	2	3	4	5
Carbonate of lime	88.64	84.01	88.00	82.00	84.02
Carbonate of magnesia	6.77	1.88	4.00	3.00	5.33
Insoluble residue	2.15	12.19	6.40	13.00	7.42
Oxide of iron and alumina	.....	.....	1.00	1.50	3.04
	.....	.....	99.40	99.50	99.81

Another group of analyses represents the composition of the uppermost beds of the Trenton limestone at various points in Ohio outside of the productive oil and gas-fields. This group will include the Trenton limestone of central Kentucky as well:

No. 1—Top of Trenton limestone, Piqua, Ohio.
No. 2— " " " Osborn, Ohio.
No. 3— " " " Vienna, Ohio.
No. 4— " " " Hillsboro, Ohio.
No. 5— " " " Hamilton, Ohio.
No. 6— " " " Fremont, Ohio.
No. 7— " " " Plymouth, Ohio.
No. 8— " " " Arcadia, Ohio.

	1	2	3	4	5	6	7	8
Carbonate of lime	78.7	81.8	82.43	85.00	84.70	75.74	67.5	84.23
Carbonate of magnesia	1.7	2.6	.....	2.00	1.50	13.37	11.4	5.44
Insoluble residue	17.7	14.4	8.47	11.8	12.00	6.53	16.6	8.56
Iron and alumina	1.2	1.3	.....	0.6	1.50	.....	2.6	.....
	99.3	100.1	.....	99.4	99.70	.....	98.1	.....

This group blends and crosses with group No. 2. The same rock, doubtless, appears in both tables. A fourth group is, however, added, in which the proportions of lime and magnesia are seen to be a mean between the first and second tables. The geographical locations of the points here named must be observed. They belong on the edge of the productive fields. Nos. 6 and 7 of the preceding table might, with equal propriety, find a place here.

No. 1—Top of Trenton limestone at Fostoria.—*Lord.*
No. 2— " " " Sidney.—*Lord.*
No. 3— " " " Huntsville.—*Clarke.*

	1	2	3
Carbonate of lime	61.50	62.30	57.23
Carbonate of magnesia	27.30	28.30	33.16
Insoluble residue	5.82	4.40	4.41
Oxide of iron and alumina	.....	3.60	3.15
	.....	98.60	97.95

Still another variety of composition is found in the Trenton limestone of Ohio, and also of other adjacent states. This stratum is sometimes, though rarely, a nearly pure carbonate of lime. This phase is shown in the gas-rock of St. Henry's, Mercer county, Ohio, and also in

the glass-rock, so-called, of Wisconsin. The Trenton limestone of Carey and Dunkirk, Ohio, will probably be found to agree with the St. Henry's rock.

No. 1—St. Henry's gas-rock.—*E. Orton, Jr.*
No. 2—Glass-rock, southern Wisconsin.—*Daniells.*

	1	2
Carbonate of lime	93.64	97.92
Carbonate of magnesia	3.87	1.60
Insoluble residue	1.27	.28
Iron and alumina	.....	.82
	98.78	100.62

Many other analyses will be added and discussed in the body of the chapter, and after the facts of gas and oil production have been stated, the connection existing between the chemical and petroliferous characters of the rock will be considered. It is already apparent that two very distinct types of rock are now grouped in Ohio under the name of Trenton limestone, and that all the valuable qualities of the one are popularly, but vainly, expected from the other also.

In New York and Canada, the Trenton limestone is directly overlain by the Utica shale, a stratum of brown or black, fine-grained shale, poor in fossils, as a rule, but containing a few which are strictly characteristic, that is, that are found nowhere else. The Utica shale ranges between 200 and 300 feet in thickness in its typical localities in New York.

Above this well-marked deposit, in the eastern territory already named, another stratum of shale, sometimes interstratified with thin courses of limestone, is found. It is named the Hudson River shale. It has a maximum thickness in New York of 1,000 feet, and an average thickness of perhaps half this measure to the westward, where it becomes more calcareous. It is mainly light-blue, or greenish-blue in color, and contains many fossils.

Above the Hudson River shales is the Medina formation, red sandstone at the eastward, and red shale at the west. Its color is characteristic, as there is no similar element in this part of the scale.

The Hudson River and Utica shales, when followed to southern Ohio, seem to have lost their distinguishing lithological characteristics,

and to be blended in a common mass of blue calcareous shale, with many thin layers of interstratified limestone, both limestone and shale being highly fossiliferous. To this blended stratum the name Cincinnati group is given.

The Trenton limestone, as already shown, rises to the surface at but a single point within the limit of the state (page 5). Its nearest important outcrops are in the Blue Grass region of central Kentucky, and in the Manitoulin Islands, north of Lake Huron. In the valley of the Ohio, at Cincinnati, we are obliged to descend about three hundred feet beneath the surface to reach it.

This limestone is known to be a source of petroleum at many localities. Dana says of it, in New York, "it is sometimes bituminous, especially in its upper portions." He speaks of small quantities of oil being contained in it at Watertown, New York, and also at Montmorenci and Pakenham, Canada. Hunt asserts that it contains petroleum in its outcrops in the Manitoulin Islands. He instances one well that produced 120 barrels. In southern Kentucky and in Tennessee, this same limestone has been credited with a part, at least, of the large production of oil that has occurred there. A single well is claimed to have produced 50,000 barrels, but its oil was probably derived from the Hudson River series.

Within the last three years, the Trenton limestone has been proved to be a source of high-pressure gas, and of petroleum in considerable quantity at several points in northwestern Ohio, and later in central Indiana. Although this formation was believed to underlie the part of the state in which it has been found, and although it was known to be petroliferous in its nearest outcrops, both north and south, the occurrence of oil and gas in quantity in it in Ohio, had not only not been predicted, but was entirely unexpected. One reason why it was not expected was, that this stratum had been previously reached and penetrated in several deep borings within the state without any sign of the presence of either oil or gas in considerable quantity.

The best known of these borings was the deep well in the State House grounds at Columbus. This boring was undertaken to supply the State House with water, and it was carried to a depth of 2,775 feet. Its record is as follows, being quoted from Newberry's account in Geology of Ohio, I, 113:

SYNOPSIS OF THE REGISTER OF THE STATE HOUSE WELL.

Date.	No.	Thickness.	Depth at which struck.	Rocks passed through.	Feet bored per day.	Remarks.
1857. Nov. 4	1	123	.....	Clay, sand & gravel..	.....	Well tubed with 6-inch pipe to the rock. Inside of this a 4-inch pipe sunk several feet into the rock.
Dec. 2	2	15	123	Blackish shale	7	
Dec. 11	3	138	138	Gray limestone with bands of chert.....	5	Struck current of water at 150 ft., which washed away borings to 242 ft. Found sulphur water at 180 ft.
1858. Jan. 14	4	2	276	Very gritty rock	2	Water rose 5 ft.
Jan. 15	5	486	278	Limestones, light-colored and sandy above; darker and argillaceous below.	10	Found salt water at 675 ft.
Mar. 20	6	162	764	Red, brown and gray shales and marls...	12	Borings impregnated with salt.
April 8	7	1058	926	Blue and greenish calcareous shales...	13	Progress per day ranging from 1 to 25 ft. Much impeded by crumbling of shale strata; harder below. Borings salt.
1859. June 25	8	475	1980	Light-colored, sandy, magnesian limestone.....	4½	Water continues saline.
1860. June 21	9	316?	2459	"Whitish sandstone," calcareous..	4	Probably alternating bands of sand and limestone above. No borings preserved below 2,570 ft.; mostly washed away by water.
Oct. 1	.....	.....	2775.4	Present bottom of well in sandrock.?	.....	

The interpretation of the section as furnished by Newberry, must be in the main accepted. But one or two important corrections are made in the scheme presented below.

GEOLOGICAL SECTION OF THE STRATA PENETRATED IN THE STATE HOUSE WELL.

No.	Thickness.	Character of rocks.	Geological equivalents.	
1	123	Clay, sand and gravel.	Drift deposits.	Drift.
2	15	Blackish shale.	Ohio shale, bottom layers.	Devonian.
3	138	Gray limestone with bands of chert.	Corniferous limestone.	
4	2	Very gritty rock.	Oriskany sandstone. ?	
5	486	Limestones, light-colored and sandy above; darker and argillaceous below.	L. Helderberg, Niagara and Clinton limestones.	Upper Silurian.
6	162	Red, brown and gray shales and marls.	Medina and upper part of Hudson River shales.	
7	1058	Blue and green calcareous shales and limestones.	Hudson River and Utica shales.	Lower Silurian.
8	475	Light drab, sandy magnesian limestone.	Trenton limestone.	
9	316	White sand-rock. (Calcareous).	Calciferous sand-rock. ?	

No hint was anywhere given in the record of the well of the presence of these bituminous substances in noticeable amount. The Trenton limestone was reached at a depth of 1,984 feet, as is seen from the table above given.

A deep well was drilled in Eaton, Preble county, some years since, in search of petroleum. The drilling was begun in the Niagara limestone, and was carried down to 1,370 feet or thereabouts. The drill traversed several hundred feet of Trenton limestone, but neither gas nor oil was found in noticeable quantity after the first few hundred feet were passed through.

A number of deep wells have been drilled in the Ohio Valley near Cincinnati, which have been carried through the Trenton limestone without doubt, but only insignificant accumulations of gas or oil have been found in any of them.

These facts, drawn from widely separated localities, agreed in the negative testimony which they furnished as to the petroliferous character of the Trenton in Ohio, and seemed to set aside any presumption in its favor that might arise from the petroleum found in its outcrops in

adjacent states. The cause of these failures in southern Ohio, we are coming to understand. They depend on the chemical constitution of the Trenton limestone in that part of the state.

But in November, 1884, the drill revealed the presence of natural gas in large quantity, and directly afterwards of petroleum also, in the Trenton limestone underlying Findlay, Hancock county. Other wells drilled in neighboring towns soon proved the horizon productive at numerous points, but Findlay has remained to the present time the center of interest in the new field. On all accounts, therefore, it deserves to be treated first when the history of gas and oil in northwestern Ohio is given.

Discovery of Gas and Oil at Findlay.

Natural gas has been known to occur at and near Findlay since the country was first settled. In several springs that issue from the limestone outcropping in the valley of Blanchard's Fork, gas has always been known to escape in considerable quantity. The water of such springs was charged with sulphuretted hydrogen in all cases.

The first discovery of gas in excavations in or around the town seems to have been made in October, 1836. At a point three-and-one-half miles south of the court-house, in the northwest quarter of section five, Jackson township, a man named Wade was digging a well on the farm of his brother-in-law, Aaron Williamson. The digging had been carried down ten feet and water was found in sufficient quantity. The workmen were ready to wall the well when they were called to supper. Coming back at the edge of the evening to complete the work, a lighted bark torch ignited the gas in the well, giving rise to a slight explosion. The gas appeared in quantity enough to maintain a flame which burned, as the story goes, for three months, when the snow and rain got the better of it and extinguished it. The well was never walled nor used.

In 1838, Mr. Daniel Foster dug a well on his premises, at the corner of Main and Hardin streets, Findlay. The gas appeared in quantity and the water was too sulphurous for use. It occurred to Mr. Foster to get some good from his labor, though as a source of water the well was a failure. Placing an inverted sugar-kettle in the well, he collected the gas that rose beneath it, conveying it by means of a wooden-pipe under his house to the fireplace of one of the rooms. Here he burned it in an old gun-barrel, turning the heat to some economic account. The gas has been burning in this house from that day to the present. The house is now owned by Dr. Jacob Carr. An account of the later gas-production here was given by Professor N. H. Winchell, in Geology of Ohio, Vol.

II, published in 1874](p. 366–7). He quotes from a letter of Dr. Carr, which bears date February 4, 1872: . . . . "I have lighted my house during the last nine or ten years from an adjoining well, which, at first, was dug to the rock, seven feet from the surface of the ground, for the purpose of procuring water for house use. The gas comes through crevices in the rock and spoils the water for kitchen use. Three such wells are on my lot, which is 50 by 200 feet. I have never been able to get down to the rock without encountering this gas, and have filled up a number of wells. . . . . In 1865 a company leased the privilege of drilling on my lot. They drilled 135 feet in limestone, when the auger got fast and they gave up the enterprise. I now use gas from that well, the supply being more abundant than from those where no drilling was done. . . . .

"Gas has been struck in small quantities in various parts of the town, but unless they strike crevices there is not a sufficient supply to light a dwelling-house. . . . .

"In digging the sewers through the main street, they being an average of eight feet from the surface, ave in of sulphuretted hydrogen gas was developed which has an extremely offensive smell. . . . .

"The wells that give sulphuretted water are all from the rock. There was a well dug thirteen feet deep to the rock, striking a crevice from which issues an inexhaustible supply of highly impregnated sulphur water. . . . . A very small quantity . . . . of sugar of lead in a bucketful of this water colors it an intense black.

. . . . "The gas which I use was analyzed in 1865 by Professor Chilton, of New York City, and pronounced by him to be light carburetted hydrogen, and to have come from petroleum."

These statements, made fourteen years ago, show very plainly the state of things with reference to gas-production which has existed in Findlay since its settlement. Gas has always been known to be present here, but it has been looked on as a nuisance, as something to be got rid of, if possible. It ruined the water of many of the wells in the town proper, and it gave rise to frequent explosions where excavations were made.

The amount of gas produced was recognized by good observers as considerable. As far back as 1864, Dr. Charles Oesterlin urged the construction of proper reservoirs by a company or by the town, so that the gas could be used for illumination. He was perhaps the first person to see the possibilities of considerable or even large service from this troublesome and intrusive element. His judgment was correct, but his suggestion as to use was made twenty years too soon. The recent experience of western Pennsylvania was needed before enough persons

could be found in Findlay to follow the indications of gas supply with which all were acquainted.

In 1883 and 1884, the drilling was going on at many points in Ohio. A company was formed at Bucyrus, among other towns, and in the latter part of 1883 a well was drilled there. By this approach of the drillers, Dr. Oesterlin's interest was renewed in the Findlay supply. He corresponded with the Gillespie Tool Company, of Pittsburgh, Pa., who were sinking the Bucyrus well, and urged upon his neighbors the policy of organizing a natural gas company forthwith. In this work, he was presently re-enforced by Mr. Charles J. Eckels, an old resident of the town, who had made at about this time a visit to the natural gas regions of western Pennsylvania, and who was greatly impressed with what he learned as to the desirability and value of the new fuel.

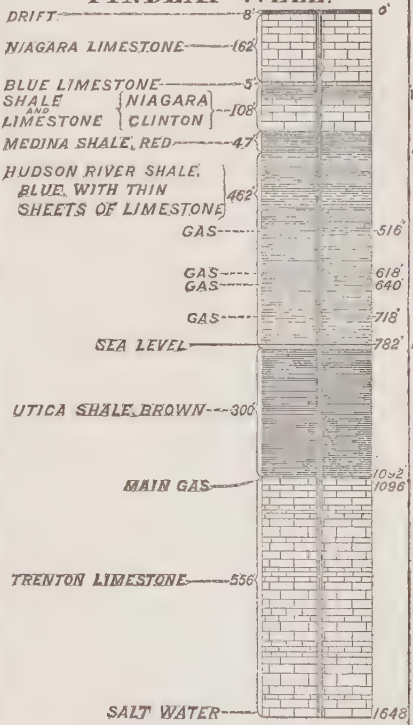
Mr. Henry Porch, collector of the town, was next interested, and thus a number of citizens were brought together in March, 1884, to organize the Findlay Natural Gas Company. The incorporators, in addition to the three gentlemen already named, were Messrs. Blackford, Glessner, Zeller, Kunz, Coons, Stringfellow and Heck. The capital stock of the company was $5,000, and Dr. Oesterlin was elected president.

Correspondence in regard to drilling was at once begun, and a contract was presently entered into with Brownyar and Martin, of Bradford, Pa., to sink a well in Findlay. Drilling was begun about October 20th on the east side of Eagle Creek, and just beyond the corporation limits. The location was made because of the presence of a well-known gas spring in the immediate neighborhood. As the drill descended, gas was found in small quantity from 314 feet downwards, but larger veins were struck at 516, 618 and 640 feet. The supply from these sources was ample to furnish steam for drilling. At 718 feet, a small quantity of oil was found. This horizon is a notable one in all of the Findlay wells, but the character of the bed that furnishes it has not yet been worked out. But at 1,092 feet, early in the month of November, a large flow was obtained. The gas was lighted and the blaze shot up 20 or 30 feet above the stand-pipe. The light could be seen for 10 or 15 miles away, on all sides. Great excitement was naturally caused by the discovery, and people flocked into Findlay by the thousand to see the strange spectacle. No measurements were made of the flow of the well, but by comparison with the yield of later wells, as estimated by the drillers, its daily production was, probably, between 200,000 and 300,000 cubic feet. On this point we have nothing but estimates, however.

The flow of gas proved thus large and constant, but still the company proceeded to drill deeper in search of a more abundant supply. The drill finally rested at 1,648 feet. Salt-water was found in consider-

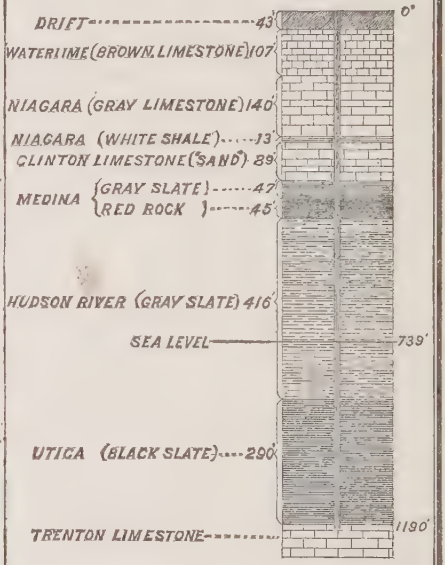
SECTIONS OF GAS WELLS.

FINDLAY WELL.

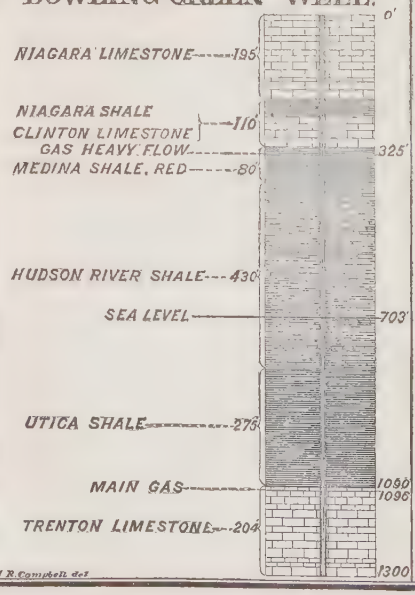


NORTH BALTIMORE WELL No 1.

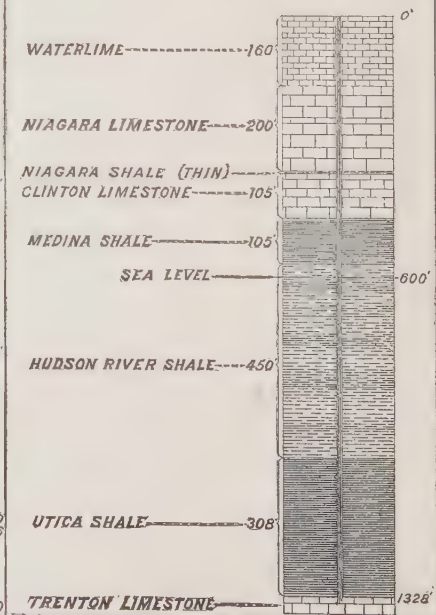
J.W. Elliott's Section.


DRIFT 43' 0'
WATERLIME (BROWN LIMESTONE) 107'
NIAGARA (GRAY LIMESTONE) 140'
NIAGARA (WHITE SHALE) 13'
CLINTON LIMESTONE ("SAND") 89'
MEDINA (GRAY SLATE 47' RED ROCK 45')
HUDSON RIVER (GRAY SLATE) 416'
SEA LEVEL 739'
UTICA (BLACK SLATE) 290'
TRENTON LIMESTONE 1190'

BOWLING GREEN WELL.



FREMONT WELL



able quantity at 1,581 feet, and its presence discouraged a much deeper descent. A heavy black oil was found in small amount in the well. There was an accumulation of it to the extent of perhaps 40 feet in the pocket at one time. Its source was not far from the point at which the gas was found. As has been stated earlier, black oil was also found at 718 feet in the well.

The record of the well, as published at the time, was substantially as follows, a few terms being replaced:

Drift	8 feet.
Limestone	160 "
Thin slate	2 "
Blue limestone	5 "
Limestone, soft	70 "
Slate	38 "
Red shale (boundaries not certain)	33 "
Gray shale (lower boundary indistinct)	424 "
Brown shale, with some changes	352 "
Solid limestone, the gas-rock, first struck at	1092 "
Gritty limestone, found at	1120 "
Limestone, found at	1360 "
Gritty limestone, with salt-water, at	1628 "
Drill rested at	1648 "

This record is represented in the accompanying diagram.

The well was cased at 257 feet, and no water entered thereafter in quantity until a depth of 1581 feet was reached. In the upper limestone, saline and sulphurous water was found at several different levels. The cost of the well was $3,200.00.

By analysis of this record, the following facts appear, viz., (1) the bedded rock was struck at a depth of eight feet; (2) there was a thickness of 237 feet of limestone in a practically continuous body; (3) below this, a body of shales, blue, red, gray and brown or black successively, was found, 847 feet in thickness; (4) a solid limestone was next found, which, beginning at 1,092 feet, held on to the bottom of the well.

This lower limestone was divided by the drillers into several sections as indicated above, but there was no urgent ground for such divisions. The limestone really constitutes a single stratum, the thickness of which was found in the well section to be 556 feet, the bottom of it being not yet reached. Only minor changes in color and composition were noted in descending.

The main stock of gas was found in the uppermost portion of this great stratum.

The record can be still further reduced by writing it thus:

8 G.

Drift	8 feet.
Upper limestones	237 "
Shales, red, gray, brown	847 "
Lower limestone, or gas-rock, struck at	1092 feet.

Interpretation of the Well-Record.

The reference of the various strata penetrated in drilling to their proper places in the geological column, does not prove to be a difficult task. The only uncertainty pertaining to it is in fixing the limits of the several strata. This, it is not always possible to do with exactness.

Fortunately, Mr. Eckels, one of the originators of the company, was able to give a great deal of time and attention to the work of securing samples of the drillings of this first well at frequent intervals, and especially at all the marked changes. These well-authenticated samples were kindly turned over to the State Geological Survey for study and analysis, and by means of them, combined with the study of drillings subsequently obtained from other Findlay wells and from other localities, a very satisfactory account can be given of that portion of our geological scale that is included in the well records.

The uppermost limestone in which the drilling begins, proves to be the Niagara limestone, and the horizon at which it is struck is near the uppermost portion of this series. The rock is quarried largely in the immediate neighborhood, and the Waterlime or Lower Helderberg series is also found and quarried near by. The 237 feet referred to the upper limestone does not, however, prove to be a single stratum. There is a thin bed of very white and fine-grained clay occurring in this series that always attracts the attention of the drillers, although it does not always find a place on the record. It is but two feet thick, according to the newspaper record quoted above, but this measurement is wrongly given. It is ten feet thick in this well, and is generally more. It is tough and waxy, and the tools are sometimes obstructed by it. It generally contains some of the smaller fossils of the formation. In all respects, it agrees in character with the thin stratum of white clay with which the Clinton limestone is terminated in southern Ohio. Its outcrop is especially well seen in the vicinity of Dayton, marking the exact boundary between the Clinton and Niagara divisions there. It seems to answer the same purpose in the deep wells of northern Ohio. A belt of soapstone or shale represents the Niagara shale in this part of the state. It has escaped recognition, or at least, record, in many of the wells, but others show it to be a distinct element in the section. The underlying Clinton seems to contain shale mingled with the limestone, agreeing in this respect with the phases of the formation in New York.

It also has a greater thickness than is found in the solid limestone stratum of this age in southern Ohio.

In other words, the so-called "upper limestone" of the Findlay wells is found, when carefully studied, to comprise the following elements, viz.:

Niagara limestone, Cedarville division, Springfield division, 100 to 250 feet; 160 feet in first well.
Niagara shale, 0 to 25 feet; 10 feet in first well.
Clinton limestone and shale, 50 to 100 feet; 80 feet in Findlay wells.

Underneath the upper limestone, 850 feet of shales are found, which the driller separates on the basis of color, classifying them as red, gray and dark or black shales. In making this classification, however, he is but following the divisions made long ago by the geologist. The red shale that he reports as thirty or more feet thick, and which, in fact, is usually more than twice this thickness, can be nothing else but the Medina shale, the western representative of the Medina sandstone of New York.

The blue or gray shale, often distinctly greenish in some of its layers, and generally carrying numerous fossils, especially in the thin leaves of limestone which are interstratified with the shale, is in the place and has all the characteristics of the Hudson River shales of New York. A thickness of 424 feet is assigned to it in the record of well No. 1, but the lower boundary is not sharp and distinct, and the facts now in hand prove that it would be better to increase this section by 100 or more feet at the expense of the division next below. The Hudson River shales can be counted, therefore, as about 550 feet in thickness in northern Ohio.

There remains to be assigned to its place in the geological column the lowest portion of the shale found by the driller. It is somewhat calcareous in composition, though not highly so. It is dark in color, sometimes brownish, sometimes blueish-black. It is 250 to 300 feet in thickness. Though fossils are rare in it, they are not entirely wanting. Careful search in the drillings revealed the frequent presence of a minute, almost microscopic form, *Leptobolus insignis*, Hall, especially in the lowest beds. This is the most characteristic fossil of the Utica shale, and to this reference all the facts given above as to composition, color and thickness, agree. There is, therefore, no difficulty nor ambiguity in resolving the great shale formation of the Findlay wells into the well-known and widely extended geological elements already named, viz., the Medina, Hudson River and Utica shales.

Equally free from obscurity or question is the reference of the one remaining element of the section, viz., the "lower limestone" or the gas and oil rock. This can not be anything but the Trenton limestone

of the general column. It agrees in all essentials with this great stratum. Fragments of characteristic fossils frequently occur. In the lower portions of the first well, the drillings showed the crystalline points of calcite that give the so-called Birdseye structure to the bottom beds of the Trenton limestone elsewhere. We are therefore safe in referring this 550 feet stratum of the Findlay well to the Trenton, including both the Galena or uppermost, the Trenton proper and the Birdseye divisions.

It is thus seen that the geological growth of northern Ohio is identical in its phases with the growth of New York and Canada. The column shown in the wells is strictly comparable in all of its main features with the column of western New York, agreeing much more closely with this than with the section that is shown in outcrop in southern Ohio and in the territory adjacent to it.

The reference here given was made known to the drillers at once, and the several elements of the scale last mentioned, viz., the Medina, Hudson River, Utica and Trenton epochs, none of which are found in outcrop in the state, in separate, unequivocal and undisputed form were at once adopted and made to enjoy universal currency. The Trenton limestone, in particular, has already become a household word in northwestern Ohio and in all the states adjacent.

A few chemical analyses of the several strata found in the first Findlay well are appended here. They were executed for the survey by Prof. N. W. Lord:

1. Niagara limestone at 180′.
2. Clinton " 225′.
3. Trenton " 1092′.
4. " " "

	1	2	3	4
Carbonate of lime	52.41	50.27	47.05	53.50
Carbonate of magnesia	41.51	40.63	33.38	43.05
Insoluble residue, silica, etc	3.92	6.60	11.73	1.70
Iron and alumina				1.25

The gas rock, as shown in No. 3, appears in a more impure form than at most other points in the field. This fact arises from the Utica shale being mixed in the drillings. The composition of the gas rock by itself is shown in No. 4.

The register of the first important gas-well of this new field has now been discussed, and the leading facts pertaining to the discovery of high-pressure gas at this point have been put on record.

The testimony furnished by the first Findlay well as to a reservoir of gas and oil below the surface was confirmed and supplemented by the records of other wells that were put down in rapid succession in this and in adjoining towns.

The discovery of gas and oil at Findlay has made a great impression on the western half of Ohio, not only, but on all adjacent states as well. In fact, no geological discovery ever made in the country, unless the original discovery of petroleum in western Pennsylvania shall be excepted, has exerted so wide-spread and powerful an influence on half of the United States, or at least on the northern Mississippi Valley, as the discovery of Findlay gas. Every county in the western half of Ohio, without exception, has already drilled one or more wells to the Trenton limestone, or at least has made a vigorous and determined effort to reach the new source of light and heat. Many counties outside this limit have spent and are still spending money lavishly in the same search. Even small villages that have heretofore counted themselves too poor to provide such fundamental requirements of comfortable living as sidewalks, street-lamps, and graveled road ways, find no trouble in raising money enough to drill two thousand feet, or more, into the underlying rocks, in search for natural gas. When such towns attain any pronounced success in their drilling, they are sometimes temporarily embarassed thereby, as there are, in many cases, no industries established in them to which a large flow of gas can be profitably applied.

Outside of our state limits, and especially in Indiana, the search has been extended, and in a number of counties with remarkable success. Real estate speculations, sometimes of a very unreasonable sort, have lately followed these discoveries, and whole communities have been worked up into an excited and irrational frame of mind. The immense importance of the business interests involved, will be subsequently pointed out.

The search for petroleum and gas, as is well known, is invested with the same sort of fascination that attends the search for other underground treasures. The element of chance comes distinctly into the account. It requires no elaborate calculation to establish the great value of a permanent flow of natural gas at the rate of one or more millions of cubic feet in a day, and, in the popular estimate, one town or one locality has as good a right to expect success in its search as another. In drilling oil or gas-wells, as in lotteries, the blanks are not

counted. It is only the successful ventures that are kept before the mind.

Then again, there are those at hand whose interest it is to foster the appeal to the drill. It is certainly no reproach to the driller that he follows the proverb, "make hay while the sun shines." Very likely he is entirely sincere in the belief that the town which proposes to drill has just as good a chance to strike gas as Findlay had. At any rate one brilliant success outweighs many failures, and he finds it easy to make effective use of the many instances at hand in which great results have followed the drilling of a test well.

An English geologist has remarked "the curious perversity of the human mind, that men prefer to take the advice of those whose interest it is to get them to spend money rather than the warnings of those who can have no interest in inducing them not to spend it." This perversity finds, as a matter of course, frequent illustration in the new field. It is especially noticeable in the continuing to drill after the gas and oil horizon has been passed. To drill deeper is the almost universal demand, when failure at the proper horizon is experienced. Thus far, unless some gas or oil is found in the uppermost sheets of the Trenton limestone, none is found below, and in but one case have valuable accessions to the supply been made more than fifty-five feet below the top of the rock. There are scores of instances now on record, all agreeing as to this point, and yet most of the wells that fail to find gas in the proper horizon are carried down 200, 300, 400 feet into the solid limestone before being finally abandoned. Such expenditures are a dead loss to the investors, and are generally of but little value to the drillers.

The same perversity shows itself in multiplying wells after one or even after repeated failures in territory which must be counted on highly probable ground as unproductive.

THE FINDLAY FIELD.

Not only was Findlay the first town in Ohio to reach gas and oil in the Trenton limestone, in point of time, but it is, also, easily first, thus far, in point of importance. The country for a dozen miles north and east of the town is counted in the Findlay field in this connection. In gas-production, indeed, no other locality of northwestern Ohio has, as yet, come into anything like close comparison with it. Its present supply is ample for any enterprises, and the possibilities of future sup-

ply seem large and promising. The town has already received an extraordinary impetus, and its business prospects seem very auspicious. A record of the new industries of the town will be appended to this section.

A brief account will now be undertaken of the development of the field since the initial well was drilled in November, 1884, the history of which has been given in the preceding pages.

No sooner had Dr. Oesterlin and his associates, the pioneers in Findlay gas-production, proved the existence of a prolific gas-rock, 1,100 feet below the surface, than other parties set out to find and test the new source of wealth. By the experience already gained, the work had been simplified and the expenses of drilling correspondingly reduced. The thickness of the upper limestone was now known, and also the horizons at which water veins were struck, and the length of the casing required to exclude the limestone water. So also the several gas horizons found in the first well were located, and especially the main one. Most important of all, the negative results, so far as gas or oil was concerned, obtained by the first company in sinking the drill through 550 feet of the Trenton limestone, discouraged all who came later from again incurring this large and useless expense. Several of the succeeding wells were, however, carried deeper than was necessary.

Before taking up the history of the wells in detail, a few facts will be given as to the geology and topography of the region to which Findlay belongs.

Geology and Topography of Findlay.

Findlay is located in the drift-covered plain of northwestern Ohio, but within the city limits and in the immediate vicinity, the beds of drift are not as heavy as are often found. They range here, for the most part, five to twenty-five feet in thickness. The limestone is laid bare in the beds of the streams, and is also struck in many ordinary excavations, as wells, cellars and sewers. On the east side of the town where all the larger quarries are located, the limestone proves to be the Niagara. In bedding and composition, it is characteristic, but it is not as rich in fossils as the upper beds of the Niagara generally are. Some fossils are found, however, and among them the following have been identified, viz., *Halysites catenulata*, *Syringopora*, a cyathophylloid coral, characteristic of the Niagara, probably *Zaphrentis Racinensis Whitf.*, a *Spirifera*, like *plicatella*, and crinoidal joints. Most are obscure and poorly preserved, but those that are found are decisive as to the age of the rock.

In these quarries ten to twelve feet are worked, and near the banks of the streams but little stripping is required. The stone lies in a very

irregular and disturbed condition for Ohio rocks. It rises and falls in waves and folds, the pitch being often as much as one foot in fifteen. This state of things is seen to good advantage at Isaac Hershey's quarries, on the banks of Lye creek, and also in the bed of Blanchard river, near the Main street bridge. At the latter point the dip is seen to be seven degrees to the westward. The surface here is marked distinctly by glacial scratches. To the west of the town, a ridge extends for some distance, and at an elevation of fifty to seventy-five feet above the general level of the country. This ridge proves to be underlain with bedded limestone, but the limestone belongs to a higher horizon than that already named. It is the Waterlime stratum that appears here the bedding of which is so uniform and characteristic for many hundreds of square miles in northern and central Ohio, that no further evidence is needed as to its geological age than this single fact furnishes.

The topography of the region is quite simple. Blanchard's Fork of the Auglaize River flows through the town in a westerly direction. As before stated, it has a rocky floor within the town limits, but its banks are not high. Its tributaries also flow in shallow valleys, most of which are floored with Niagara limestone.

The elevation of the station of the Lake Erie and Western Railroad, according to published figures, is 782 feet above tide-water. Taking this as a base, the levels of the several gas-wells have been determined, and a tabular statement of the facts will be found on a subsequent page. Aside from the limestone ridge on the southwestern side of the town, the variation in level of the surface of the town is quite small, and, in fact, it needs good engineering to give proper fall to drains and sewers.

No evidence of any unusual disturbance in the rocks of this district is apparent in any surface indications, further than such as have been already pointed out, as, for example, in the Hershey quarry. While the irregularities referred to are unusual, they do not appear to be large or continuous, and, in fact, the records of the gas-wells on the east side of Main street show a surprising degree of uniformity in the underlying strata. The gas-wells in other portions of the town have, however, established the unexpected and surprising fact that there is in Findlay a heavier dip, or, in other words, a steeper slope of the strata than is to be found, so far as is now known, at any other point in Ohio except one. The Sinking Springs fault, on the north line of Adams county, shows a greater disturbance than that recorded here, but a dip of nearly 150 feet in less than half a mile has been found, by comparing the records of two gas-wells in Findlay. The facts will be be better understood when the registers of the several wells have been given and discussed.

Records of Findlay Wells.

The history of the discovery of natural gas in the Trenton limestone, at Findlay, has already been given, and with it the record of well No. 1.

Well No. 2. The Gas Works Well. The Findlay Gas-Light Company, that has been supplying the town with coal gas from a small plant, for a number of years, was the first to follow the successful experience of the Natural Gas Company by drilling. The interest of this company in the discovery is obvious. The Natural Gas Company was making ready to utilize its discovery by laying mains from its well into the town, and the competition of artificial gas with the new supply was altogether out of the question. This new well was located on the Gas Company's lot and within a few score of feet of the works. Drilling was begun about December 20, 1884. The work proceeded uneventfully and the record of the first well was duplicated in all essential points. The upper limestones were found to be 245 feet thick. The casing was set at 260 feet. Small gas veins were struck at 527, 623 and 700 feet, about as in the pioneer well. The main gas rock was reached at 1,090 feet, but the drilling was continued to 1,200 feet. The well was completed early in January, 1885. The flow of gas never quite equaled that of the first well. Its daily production may have reached 200,000 feet. It did not probably exceed this figure. The well being closed, the pressure in the gauge rose to seventy-five pounds in twelve minutes. The gas was turned directly into the city mains and found a market from the first. The well is now one of the smallest producers in the circuit. Its record is as follows:

Elevation of casing above tide	775.50 feet.
Surface of Trenton limestone below tide	314.50 "

Well No. 3. The Marvin Well. This well is located on Front street, about 250 feet east of Main street, and about one square south of the river. The casing is 773.87 feet above sea level, and the Trenton limestone 346 feet below.

It was drilled by W. K. Marvin & Sons, to furnish power for their machine shop, the well being located in the lot belonging to the works. It was subsequently bought in by the Findlay Gas-Light Company, and is now in the general circuit of this company.

Without previous experience in drilling, they carried on the work without outside help and reached the gas rock successfully, though requiring a little longer time than was used in drilling other wells. The rock section reported in their register agreed in all the main items

with the sections of the first two wells, but the yield of gas proved smaller than in either of the others. Within a week or two after the gas was reached, the anemometer measurement applied to the well made the daily outflow 81,244 cubic feet per diem. Mr. Marvin is confident that the flow has increased since the well was opened. The well shows 400 pounds pressure in the morning after being shut off all night, as do all of the Findlay wells, without exception, until obstructed with oil and brine.

The upper limestones were about 250 feet thick, the casing was set at 271 feet, the lower gas rock was reached at 1,120 feet, and the main gas supply at 1,130 feet, and the drill rested at 1,155 feet. The well was finished in June, 1885. Mr. Marvin makes a statement that illustrates more strikingly than any other fact obtained in the field the communication that exists between different portions of the oil rock. The gauge in his well, which had been standing uniformly at 100 pounds closed pressure, went up to 525 pounds on the morning after the Putnam street well was torpedoed. The mercury in a gauge was also displaced by the shock, apparently, part of it being thrown from the open end of the gauge. The uniformity of pressure, already remarked upon, presupposes such free communication, but the conclusion is strengthened by such a fact as this.

Well No. 4. *The Adams Well, or Foundry Well.* This well was completed on the 28th day of May, 1885. It is located at the Adams Foundry and Machine Shop on Main Cross street, nearly opposite the station of the Lake Erie and Western Railroad. It is a little south of west from the Marvin well, and about three-eighths of a mile distant. It was drilled by the Findlay Gas Company (coal gas), thus making their second well. A chief purpose was to obtain power for the works where it is located.

The registers of the three wells that had been drilled (the third was not completed when this was begun) had agreed almost exactly as to the geological section traversed by the drill. Below the drift, which was of variable thickness, there was a limestone formation about 250 feet thick, underneath which 850 feet of shale were found, covering the Trenton limestone, which is the gas-rock. Mr. W. M. Martin had charge of the work on wells Nos. 1 and 2, and finding their record repeated in well No. 3, as far as it had gone, naturally concluded that a similar section would be found in the Adams well, which also he was drilling. But this geological inference proved to be unfounded, and the progress of his work brought out the surprising fact, that in the monotonous, drift-covered plains of northwestern Ohio, there are far greater structural irregularities in the way of heavy dip than is to be found

among the valleys and hills of even the eastern portion of the state, on the border of the great disturbances that have lifted Pennsylvania and Virginia into mountain folds.

In the Adams well, 350 feet of the upper limestone series was found, instead of 245 feet, as shown in the three other sections. The well-marked horizon of the Medina shale, in other words, had descended about 100 feet in a third of a mile. The upper limestones had been reenforced by the overlying Waterlime which, as has been shown, is found within the limits of Findlay. In all other respects, however, the new well followed the records of its predecessors. The Trenton rock was struck at 1,188 feet, or just about 100 feet lower than in the other wells. This shows the great shale deposit to maintain its regular thickness here of about 850 feet.

In the upper limestone, at a depth of 105 feet, a thin bed of "sandstone" was reported, and a few feet below it, a "quartz rock" was reported, through which the drill laboriously descended, according to the accounts given, at the rate of one or two feet *per diem*. The sandstone sheet comes in, apparently, at the place of the Hillsboro sandstone of the general column, which is interposed between the Niagara and Waterlime. It is not shown, however, in outcrops of this line of junction in northern Ohio, so far as is known. The silicious deposit, referred to as "quartz rock," is, probably, one of the flinty courses that find frequent place in our limestone series.

In gas-production, the Adams well proved much stronger than either of those that had preceded it. It was estimated, by the drillers, to yield six or eight times as much as the first well. The flow, as determined by the anemometer on June 3, about a week after the gas was struck, was at the rate of 1,296,000 cubic feet *per diem*. The use of the anemometer for measuring the flow of gas-wells was first suggested, so far as is known, by Mr. Emerson McMillin, Superintendent of the Columbus Gas Works, and it was first applied by him to the measurement of the Adams well, with the results already given. It has since been compared with other modes of measurement, and has been found to be fairly reliable. It is not adapted, however, to wells of the highest pressure. The current can, however, be divided in such cases so as to admit of its use. This subject of measuring the production of gas-wells will be discussed further, in a subsequent chapter.

Oil appeared in the Adams well at the same time, and at the same horizon, at which the gas was found. After the well was brought into the system of city supply, the oil was seen to be increasing in amount. During the last four months of 1885, about five barrels of oil were brought up with the gas each day, but without much diminution in the

quantity of the gas. In January, 1886, however, a change appeared. The Karg well, which is by far the strongest well of the Findlay field, was finished about January 20, and simultaneously with its astonishing production, the gas of the Adams well fell off, while the oil production increased from five to fifteen or twenty barrels *per diem*. At the present time it is an oil-well rather than a gas-well, the gas being very much obstructed by the oil. It was reported as producing twenty barrels quite regularly during the latter part of 1886. A few boilers were still supplied from it at this time. The well is now abandoned.

The elevation of the casing above mean tide is 782.67 feet. The Trenton limestone was found at 1,188 feet, or 405.33 feet below tide.

Well No. 5. The Lima Road Well. This well was drilled in July and August, 1885, the drilling occupying about thirty days. It was put down by the Findlay Gas-Light Company, W. M. Martin being the contractor. Its register closely agrees with the register of the Adams well. The upper limestones were 350 feet thick. The top of the Trenton was struck at 1,188½ feet. The elevation of the well-head being 785.90 feet above tide, the upper surface of the Trenton is seen to be 402.60 feet below tide. Gas was found in the usual shale horizons. In the main rock, it was first shown in quantity at 1,194, again at 1,200, and also at 1,208. The drilling was continued to 1,215 feet. In the last bit, as was thought, oil appeared. The drilling was at once suspended, and the attempt was made to arrest the ascent of the oil, by plugging the well below the lowest gas vein, viz., at 1,208 feet. For a time this was effective, but at a later date, oil of inferior quality came into the well, apparently in the gas horizon, and in connection with it, salt-water. The well now brings up five or six barrels of oil and salt-water each day, and the pressure of the gas is notably decreased thereby.

Mr. Martin estimated the original production of this well to be about three-fourths that of the Adams well, or about 750,000 cubic feet per day. He gauged the initial pressure in a rough way, by observing the amount registered when the wells were shut in for one minute each. By this test, this well gave 105 pounds, against 140 pounds in the Adams well. After the well was brought under control, it showed a pressure, after being shut off all night, of 400 pounds per square inch. This, it will be remembered, is the normal pressure of the gas in the rock. At a later date, however, the morning pressure rarely exceeded 270 lbs., and was frequently as low as 250 pounds. In April, 1886, the gauge showed fifty pounds pressure when the well was shut off five minutes. Quantitative determinations cannot be based on these observations, but the well is obviously losing pressure and production to a considerable ex-

tent. Unfortunately its oil has not thus far been of a quality to make compensation for the falling off in gas. Much of the oil is burned on the ground for the sake of getting rid of it. Since the preceding statements were made, the well became altogether useless, and it was accordingly decided to drill it deeper and torpedo it, to convert it, if possible, into an oil-well. The shot, however, in connection with the deeper drilling, unlocked a flood of salt-water, which proved fatal to the well, and it was finally abandoned in the fall of 1886.

Well No. 6. The Barnd Well. This well was the most southerly of the series at the time it was drilled. It belongs to the Findlay Gas-Light Company, and was drilled by W. M. Martin, in August, 1885. It is located on the land of E. Barnd, Esq. The location was made with reference to obtaining a supply of gas for lime manufacture, Mr. Barnd having several kilns already in operation on his land at no great distance. Inasmuch as this business demands fuel only through the summer months, the well was connected with city mains, so that all surplus could be turned to account.

The register of the well is very nearly like that of the preceding. The elevation of the casing above tide-water is 788.31 feet. The Trenton limestone was struck at 1,182 feet, its surface thus being 393.68 feet below sea-level. The upper limestones were 334 feet in thickness.

The line of strike for this immediate district can be approximately located by the three wells last described. They all find the Trenton at nearly the same level:

No. 4, reaching it at (below tide)	405.33
No. 5, " " "	402.60
No. 6, " " "	393.68

A line drawn through Nos. 4 and 5 bears N. 10½° W.

The Barnd well had the same initial pressure that the Lima street well showed, viz., 105 pounds, when the well was shut one minute. It had not been invaded by oil or salt-water to any great extent, when last observed and it is reported as maintaining its normal pressure of 400 pounds when shut off for a number of hours. It has been a reliable and valuable well, but the reports of 1886 indicate that the salt-water is following the gas quite closely. For this reason it has been withdrawn from the pipe-line, and is used only in the lime kilns.

Well No. 7. The North Findlay Well. This well was also drilled by the Findlay Gas-Light Company, Mr. W. M. Martin being the contractor. It was put down in September, 1885. The elevation of the casing above tide-water is 776.28 feet. The upper limestones were found to be 280 feet thick. The Trenton was struck at 1,120 feet, or 341.72 feet below sea-level.

The well was finished at 1,171 feet. The flow of gas was by far the most vigorous that had yet been found in the field. After packing, the pressure rose 200 pounds in forty seconds, and in a two-inch lead pipe, sixty-four feet long, the open pressure was reported twenty-five pounds. Mr. Martin counted its production fully twice as large as that of any previous well in the field. On the basis of the open pressure reported, the flow is 3,335,000 cubic feet per day. It remains a very vigorous and serviceable well.

Well No. 8. *The Matthias Well.* This well was drilled for the Findlay Gas-Light Company in the fall of 1885. It was completed on November 6th. Facts already in hand led the company to expect oil here rather than gas, and the well was handled with this object in view from the first.

The elevation of the casing above tide-water is 783.55 feet. The drift beds were found twenty-eight feet thick at this point. The upper limestones were 389 feet thick. The Medina is reported as thirty feet (red rock). The Trenton limestone was struck at 1,265 feet, which shows its surface to be 481.45 feet below sea-level.

At 1,278 some oil was obtained. At 1,280 a little gas appeared, and at 1,289 salt-water was found coming in. The well was drilled to 1,321 feet and was torpedoed at fifteen feet from bottom with a 32-foot shell, containing 100 quarts of nitro-glycerine. The shell was exploded at two p. m. For the balance of the afternoon the well flowed at the rate of 300 barrels per day. The tubing was put in on Saturday, the 7th. For the next day the production was at the rate of about ten barrels per hour, gradually decreasing, however, until on Monday the rate was sixty-five to seventy-five barrels per day. It soon settled down into a periodically flowing well. Once in twenty-four hours it delivered oil, its established rate being about thirty-five barrels a day. It seldom misses its production, but it does not maintain extreme regularity. There is not much gas produced between the flows. The oil is of the same character with the oil from Lima, and will be described when that part of the field is reached. The well was packed at eighty feet above the bottom.

This was the first oil-well proper of the Findlay field, and as such, its history is important. The development of the oil field began at this time and place.

Well No. 9. *The Putnam Street Well.* This well was drilled by a company of the citizens of Findlay, who associated themselves for this single purpose. It was drilled in the fall of 1885, by W. M. Martin, contractor.

The location proved to be an unfortunate one, and the well, though not absolutely dry, does not appear to be valuable.

Its record is as follows:

Elevation of casing above sea-level	783.90	feet.
Thickness of upper limestones	400	"
Trenton limestone struck at	1,236	"
Trenton limestone, upper surface, below tide	452.10	"

It is seen from these facts that the well is located beyond the gas territory, and at the bottom of the steep slope which has already been shown to be so important a factor in this field. It might be expected to be an oil-well, however. It was torpedoed with this reference, but there were no indications that it would make at the best more than a ten-barrel pumping well, and consequently it ranks as a failure, the first in the Findlay field. It was drilled to 1,312 feet; at 1,272 salt-water came in quite freely. The influence of the shot exploded in the gas-rock of this well upon other wells in the vicinity, has already been noted, in the account of the Marvin well, No. 3.

The failure of this well ought to occasion no surprise. The oil-rock is seen to be at a low level, and there is nothing whatever to warrant the expectation that all portions of it will prove productive. Thus far every well had yielded either gas or oil, and, therefore, no one was prepared for failure here, but a larger experience will, undoubtedly, show other wells in the same category within the limits of the Findlay field.

Well No. 10. *The Kirk Well.* This well was drilled at the flouring mill just east of the Gas-House Well (No. 2), in the fall of 1885, the single object being to secure power for the mill. It was sunk rapidly and obtained a moderate flow of gas. Though one of the lighter wells in production, it furnishes an ample supply for the purpose for which it was drilled. Its production has diminished considerably within the last year.

The casing stands at 777.15 feet above mean tide, and the record of the well is said to be identical with that of No. 2, so far as the changes of rock are concerned. It was drilled to a depth of 1,171 feet.

The later facts in regard to it are of interest enough to be reported. The cost of the well equipped for its present service, was $1,584.33. Including the pipe line, the cost was $1,800. This line extends from the flouring mill to the woolen mill, and to 12 adjacent houses. The supply is not equal to this entire demand. At the end of the first year it had furnished the mill with $1000 worth of fuel, in addition to the house supply above noted. When all is shut off except the flouring mill, the pressure

does not now rise beyond 180 lbs. It stood at 230 lbs. under like conditions one year ago. A like reduction is understood to have continued through 1887. On Sundays, when the mill is shut off, the well shows the normal pressure of the field, viz., 400 lbs.

Well No. 11. *The Altman Well.* This well is located near the Eagle Creek quarries, on the east side of the town. It was drilled by W. M. Martin for the Findlay Gas-Light Company, the work being done late in the fall of 1885. It agreed, in all leading particulars, with the Pioneer well, and also with Nos. 2 and 10. The elevation of the casing above tide is 783.67 feet. The limestones of the upper series were found 250 feet thick. The Trenton limestone was reached at 1,090 feet, according to the record. This measurement shows the Trenton to lie a little closer to the surface here than at any other point in the field, viz., at 306.33 feet below tide-water. The well is, also, by a trifle, the shallowest of the entire series thus far drilled, the bottom being 1,142 feet from the surface of the ground.

The gas is used for power in pumping and drilling in the quarries, and the surplus is turned into the city mains. It is a moderate well, its flow being estimated about the same as that of the Barnd well and of the Lima Road well in its best days.

Well No. 12. *The Briggs Well.* This well was estimated to be third, or, perhaps, second in production in the series so far drilled. It is situated on the north side of the river, nearly opposite the mouth of Eagle Creek, and on the line of the Toledo and Southern Railway. It was drilled to supply power to the works of the Briggs Edge-tool Company, the first enterprise of importance to be established in Findlay to secure the advantages of the new fuel. The contractors who drilled the well were Baker and Marvin. The well was brought in about the middle of January, 1886, and only three days before the famous Karg well reached its enormous flow. For this brief interval it was in first rank in production among the Findlay wells.

The "sulphur vein" of gas, here found at 746 feet, is separated by packing from the main vein. This is the only well that has been treated in this way. No advantage is apparent in this practice, and it entails some additional expense. This upper vein proves quite vigorous. An anemometer measurement taken on April 18, showed its daily volume to be 223,200 cubic feet, and the entire production was not included.

The elevation of the well-head is 779.17 feet above tide. The depth of the well is reported at 1,164 feet, but the exact depth of the gas-rock cannot be given. It was very near 1,100 feet. The record was regular and normal in all particulars. The outflow of gas from the Trenton

rock is large and constant. Measurements executed on April 18, 1886, made the well third in the list of Findlay wells, and it is but little behind the Cory well, which was second at that time.

Its production is as follows:

Main vein	2,103,840	cubic feet.
Sulphur vein	223,200	" "
Total	2,327,040	" "

There is a small addition to be made for the unrecorded balance of the upper vein.

Well No. 13. *The Karg Well.* The well that we now reach in our review is not only first by a long interval in the Findlay field, but it is as decidedly the greatest gas-well of recent years in Ohio. (These statements were made before the Van Buren well was drilled. It has proved to be a somewhat larger well than the Karg.) Whether any well equal to it has ever been found in the state is a question. According to the accounts that come to us of the first Neff well, which was drilled in the northwest corner of Coshocton county, there must have been an enormous flow of gas from it for a considerable time. Other large outflows have been struck in the southeast quarter of Ohio from time to time, in early years in the search for brine, latterly in the search for petroleum and for gas, but we have no measurements nor even careful estimates from any of these sources.

The Karg well has given to a great number of people their first and only experience of a high-pressure gas-well of the first class. It is exceptionally well located for this purpose. It is situated in a thriving county town, which is crossed by three lines of railroads, the well itself being within a few hundred feet of the most important station. Findlay had already become famous for its supply of natural gas before this great volume was unlocked. As many as 3,000 people are said to have gathered in a single day to see the strange spectacle that the pioneer well presented, but the Karg well so far surpasses these early outflows that they seem insignificant beside it.

The attention it has attracted corresponds to its volume. The roar of the burning well can be heard for two or three miles, and its light can be seen for thirty-five or forty miles on all sides. Excursions are organized from adjacent cities and towns, and manufacturers and capitalists have been led in from distant localities. It has done more to give standing to the new field than all the other elements, for here is seen a well whose volume and energy are fairly comparable with the great wells that supply Pittsburgh and other points in western Penn-

sylvania. If inferior to some of them in daily production it still belongs in the same class with them.

Measurements executed for the Survey by Professor S. W. Robinson, of the Department of Mechanical Engineering in Ohio State University, show the Karg well to be producing each day 12,080,000 cubic feet of gas from a 4-inch pipe. The gas seems quite dry, but a little oil appears along the lines of pipe which convey it.

The well was begun in December, 1885, by the Findlay Gas-Light Company, Mr. W. M. Martin being the contractor. The work of drilling proceeded without interruption, only twenty-four days being used to the end, the gas-rock being reached at a depth of 1,118 feet. The casing stands at 771.08 feet above tide, the well being located in the valley and upon the bank of Blanchard River. The Trenton limestone is seen to be 347 feet below tide. The drift was found twenty-four feet thick, and in fact the derrick was moved once before the rock was reached, on account of a bowlder found in the way. The flow of gas from the top of the rock was not important, but at 1,132, and also at 1,138 feet, large accessions were made. The drill went down a few feet further without interruption, but at 1,144 feet, or at a depth of twenty-six feet in the limestone, an enormous volume was unlocked, against which the drill was powerless to advance. The last cuttings were brought up by the current in good-sized fragments, which are very porous and highly crystalline.

Well No. 14. *The McManness Well.* This well was drilled on Crawford street to supply the oil-mill of McManness and Seymour. The drilling was done by Baker and Marvin in February, 1886. It was begun on the first of the month, and was finished in nineteen drilling days. The usual sulphur vein at 700 ft. was found. The lower limestone was reached at 1,120. The drill was stopped at 1,146 feet. The supply is abundant, the gauge standing steady at 370–390 pounds after all that the mill requires is used. The height of casing above sea-level is 782.94 feet. The top of the Trenton limestone is 337.06 below sea-level, according to the facts reported as to depth.

Well No. 15. *The Cory Well.* This well is the first drilled by the North Findlay Gas and Oil Company. It is located on the Defiance road, and a little more than 2,000 feet due north of the Karg well. It was drilled in March, 1886, by E. C. Taylor, contractor. The height of the well-head above the sea is 781.33 feet. Its register is as follows:

Drift—blue clay	36 feet.
Upper limestone—Niagara limestone, 150′; Niagara shale, 30′; Clinton limestone, 70′	250 feet.
Casing set	298 "
Trenton limestone found	1,132 "
Well finished at	1,185 "

The Trenton limestone is 350.16 feet below tide.

The gas came gradually from eight feet below the surface of the Trenton for forty feet. There was at no point any extraordinary accession, but the volume grew steadily with every blow of the drill.

The Cory well appeared to stand second in the list of Findlay wells at the time of its completion Measurements taken on April 18, 1886, made its daily product 2,471,040 cubic feet. This puts it a little in advance of the Briggs well, but the two are very nearly identical in daily production. It has since been purchased by the city for the public supply.

Well No. 16. *The Jones Well.* This well was drilled for E. P. Jones, Esq., in March, 1886, by Baker and Marvin. It is located on Crawford street, and but a short distance west from Main. It is designed to supply power for works that can occupy the planing-mill on the premises.

The register of the well is as follows:

Elevation above tide-water	783.69	feet.
Drift	8	"
Upper limestone about	275	"
Cased at	287	"
Trenton limestone struck at	1,112	"
Depth of Trenton below tide-water	328.31	"
Light-colored, hard rock struck at	1,121	"
Continued to	1,141	"
Gas not abundant until	1,141	"
Gas increased for twenty feet	1,160	"
Depth of well	1,179	"

The flow of this well was tested before the drilling was entirely finished, by the anemometer, and the daily yield was found to be 707,933 cubic feet per day. A week after it was completed the flow was found to be 1,119,200 cubic feet. A third measurement several weeks after the second gave the same result, exactly.

Well No. 17. *The Matthias Well, No.* 2, *or The Cemetery Well.* This well is located nearly due north of the Matthias No. 1. It was drilled for oil, and was brought in successfully on the 10th of April, 1886. The well-head is 782.16 feet above the sea. The Trenton limestone was struck at 1,252 feet. The limestone is thus seen to be 470 feet below sea-level.

The well was cased at 420 feet a little below the upper limestones. The Medina shale (red rock) was found at 460 feet. The upper portion of the Trenton proved soft and sandy for this rock.

Outside of Findlay, but in the immediate neighborhood, a well was drilled in the fall of 1885 for the Trenton Rock Oil Company, by W. M. Martin. The well was located on the Firmin farm, a mile or more northwest of Findlay. The elevation of the well-head is about the same as the wells already reported, viz., 780 to 790 feet above tide. The upper

limestones were found 440 feet thick. At 470 feet, the red Medina shale was struck. It continued thirty feet. At 1,260 feet or 450 to 460 feet below tide, the Trenton limestone was reached. At 1,266, a little gas was reported, and at 1,270 a small vein of salt-water. A little oil came in at 1,276 and a heavy vein of salt-water at 1,288 feet. At 1,290 feet a little more oil appeared. The well was finished at 1,334 feet, but it was a complete failure.

A list of the wells of the Findlay field complete to April 1886 is herewith given:

Number.		Height of casing.	Trenton limestone below tide.	Depth of well.
1	East Findlay	779.44	312.56	1,648
2	Gas-works	775.70	314.50	1,200
3	Marvin	773.87	346.13 ?	1,155
4	Adams	782.67	405.33	1,207
5	Lima street	785.90	402.60	1,215
6	Barnd	788.31	393.68	1,225
7	North Findlay	776.28	341.72	1,171
8	Matthias, No. 1	783.55	481.45	1,321
9	Putnam street, dry	783.90	452.10	1,312
10	Kirk	777.15	314.50	1,171
11	Altman	783.67	306.33	1,142
12	Briggs	779.17	330. ?	1,175 ?
13	Karg	771.08	346.92	1,144
14	McManness	782.94	337.06 ?	1,146
15	Cory	781.83	350.16	1,185
16	Jones	783.69	328.31 ?	1,170
17	Matthias, No. 2	782.16	469.84	1,314
18	Taylor	783.62	480.00	1,280

From this table it will be observed that but one out of seventeen wells had proved unproductive up to this time. The territory was thus shown to be unusually reliable.

Production of the Field.

The total gas production of the wells at this date was about 25,000,000 cubic feet per day, as commonly counted. It is not to be understood, however, that this entire amount was at any time available for actual use. The measurements were made from the initial and presumably the largest production of the wells, and also were made at the well-heads, and often from the casing at that. When the wells are packed and tubed with smaller pipe, and especially when the gas is conveyed by the distributing lines through the town, a considerable reduction is encountered, no record of which is found in these reports. The loss from transportation is, however, less in Findlay than at most other points, the wells being at the doors. Such measurements are, however, valuable in showing the normal energy and productiveness of a field.

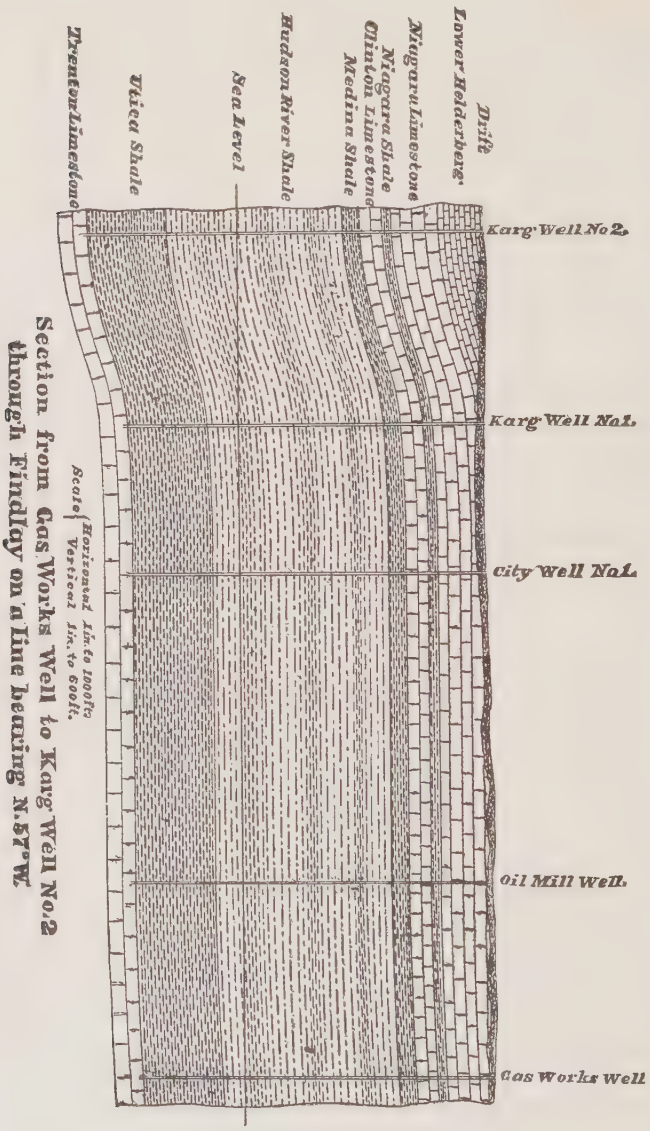
But counted in any way, the production of Findlay gas was up to this time vastly in excess of all the demands of the town. A tenth or twentieth, even, of the supply would have been ample for every use for the year 1886.

Obtained as it was in enormous volume and at insignificant expense and with no signs of reduction or failure apparent, and especially falling into the possession of a community entirely without experience as to the nature of petroliferous supplies, a very reckless mode of use was introduced, to which was added a more reckless and even an unpardonable waste. There were several months in the early part of 1886 in which not less than 18,000,000 cubic feet of the best fuel known to man were blazing into the air every day in and around Findlay. The Karg well is responsible for a large part of this loss. Its great volume made it hard to subdue, and this fact furnishes some excuse for the enormous drain that it inflicted on the stock of the Findlay reservoir during the four months that it was uncontrolled. The total loss to the field from this single source cannot be less than 1,500,000,000 cubic feet of gas.

The progress of Findlay and its new interests since the date abovenamed has been remarkable. This progress has not consisted so much in unlocking more gas from its great reservoir, though several new wells have been brought in, as in utilizing what had already been secured. In this short interval, the town has become an important manufacturing center. Its growth has been in a measure proportioned to its unparalleled supply of fuel, and it is still going forward on a very large and promising scale.

Structure of the Field.

It is not counted necessary to follow further the records of individual wells, except in cases of unusual ones. The laws of the field are to be


Drift
Lower Helderberg
Niagara Limestone
Niagara Shale
Clinton Limestone
Medina Shale
Hudson River Shale
Sea Level
Utica Shale
Trenton Limestone
Karg Well No 2.
Karg Well No 1.
City Well No 1.
Oil Mill Well.
Gas Works Well
Scale { Horizontal 1 in. to 1000 ft. Vertical 1 in. to 600 ft.
Section from Gas Works Well to Karg Well No 2 through Findlay on a line bearing N. 57° W.

found in the figures already given, and the new experience is mainly within the limits of the first tests. Dry gas comes from the Trenton limestone when it holds a level of 312 feet below tide to something below 350 feet below tide. The original level of dry gas reached down to 400 feet below tide, but this lower portion of the rock has been overrun with oil or with oil and salt-water. The strongest wells obtain their gas from 330 to 350 feet below tide. The oil level, on the other hand, extends from 400 feet to nearly 500 feet below tide. The latter level is the down-

ward limit or dead-line in the field, below which nothing of value is found. Salt-water rises in this outside territory to within 100 or 200 feet of the surface and sometimes it even overflows. The greatest oil production is found at 460 to 480 feet below tide.

The geological structure of Findlay also comes out to view in the same sets of figures. Two terraces of Trenton limestone, separated by an interval of 150 feet, are seen to be connected by a steep slope, on the edge of which the Karg well is located, and half-way down the Adams and Barnd wells are found. These facts are represented in the accompanying diagram, in which an accurately drawn section from the gas-works well to the Karg well, No. 2, is shown. The latter is an oil-well of moderate capacity. From the Karg well, No. 1, to Karg, No. 2, the descent of the Trenton is 121 feet, the elevations of the surface being the same, and the distance between them being but little more than 1,200 feet.

Composition and Uses of Findlay Gas.

The question, what is natural gas, is as hard to answer as the question, what is coal. Both substances sweep through a wide range of chemical composition, without losing their names. The fire-damp of the mine is natural gas; so, also, are the inflammable gases arising from the decomposition of organic matter.

The gas released by the drill from its rock reservoirs consists largely of what is commonly known as marsh gas or light carburetted hydrogen, the chemical composition of which is expressed by the notation CH_4. But with the marsh gas are varying proportions of numerous other simple and compound gases, including the elements of the atmosphere, The best analyses of Pennsylvania gas are those of Mr. S. A. Ford, chemist of the Edgar Thompson Steel Works. They have been widely quoted, as they deserve to be, on account of the surprising and important character of the information that they furnish.

They prove that the gas in use at Pittsburgh is unstable in composition, and that no one analysis, however accurate, would do any justice to the facts.

Its composition, as determined by the average of six analyses, (1) is given by Mr. Ford as follows: the composition of three of the samples is also added, (2), (3) and (4), to show the range:

	1	2	3	4
Marsh gas	67.00	49.58	57.85	75.16
Hydrogen	22.00	35.92	9.64	14.45
Ethylic hydride	5.00	12.30	5.20	4.80
Olefiant gas	1.00	0.60	0.80	0.60
Oxygen	.80	0.40	2.10	1.20
Carbonic oxide	.60	0.40	1.00	0.30
Carbonic acid	.60	0.40	0.00	0.30
Nitrogen	3.00	0.00	23.41	2.89

The samples were taken from the same well on different days of two months. Such variability would be expected to produce more irregularity in use than has been reported. It must certainly be an advantage to the user to adjust the supply to the work to be done, and to know that, aside from the influence of atmospheric changes, he can be sure of his result.

This advantage of constancy of composition belongs to the gas derived from the new horizon. Findlay gas was first accurately analyzed by Prof. C. C. Howard, for the Ohio Geological Survey, in 1886. Its composition was found to be as follows:

Marsh gas	92.61
Olefiant gas	0.30
Hydrogen	2.18
Nitrogen	3.61
Oxygen	0.34
Carbonic acid	0.26
Carbonic oxide	0.50
Sulphuretted hydrogen	0.20

After an interval of several months a new analysis was made, and the figures were found to agree with those previously obtained within the limits of error involved in the processes themselves. More significant still are the results of Professor Howard's re-determination of Findlay gas, for the United States Geological Survey, in the summer of 1887. To these results, which agree as closely as could be desired with the figures originally obtained, are added the composition of Fostoria gas, St. Mary's gas, and the gas of four well-known centers of production in the Indiana field, viz., Muncie, Anderson, Kokomo and Marion. The very important fact is brought to light that all of this production is of one piece. The differences in results would all be included within the limits

of error in the processes, and as wide a range could be obtained from analyzing one and the same specimen of gas.

The figures are given below:

	1	2	3	4	5	6	7
Hydrogen	1.89	1.64	1.74	2.35	1.86	1.42	1.20
Marsh gas	92.84	93.35	93.85	92.67	93.07	94.16	93.58
Olefiant gas	.20	.35	.20	.25	.49	.30	.15
Carbonic oxide	.55	.41	.44	.45	.73	.55	.60
Carbonic acid	.20	.25	.23	.25	.26	.29	.30
Oxygen	.35	.39	.35	.35	.42	.30	.55
Nitrogen	3.82	3.41	2.98	3.53	3.02	2.80	3.42
Sulphuretted hydrogen	.15	.20	.21	.15	.15	.18	.20
	100.00						

1. Fostoria.
2. Findlay.
3. St. Mary's.
4. Muncie.
5. Anderson.
6. Kokomo.
7. Marion.

These are remarkable and instructive results. From one end of the new field to the other the composition of the gas is the same, and all the popular judgments as to differences in this or that particular are seen to be baseless. Such constancy is as surprising in the light of the experience of other fields already alluded to, as it is desirable.

The specific gravity of the gas, as calculated by Prof. Howard, on the basis of the first Findlay analysis, is .566, or practically .57. In one hundred cubic feet there are 125.8 grains of sulphur.

The one main element of value in natural gas is its heating power. It supplies light also to some extent, but its value is less for this use. Like all other heat and light and power that man is able to use, this is undoubtedly originally derived from the sun through the agency of life. We know no other source of such accumulations.

The heat of natural gas depends upon its chemical composition, and varies with every change in composition.

The most careful statements as to the heating power of Pennsylvania gas are those prepared by Mr. S. A. Ford, on the basis of the analyses already reported. Professor Lesley has summarized these results in the last annual report of the Pennsylvania Geological Survey, and his results are adopted here.

The theoretical value of 1,000 feet of Pittsburgh gas (average composition given above) is 210,069,604 heat units. But 1,000 cubic feet of gas weigh thirty-eight pounds avoirdupois. The theoretical value of this amount (thirty-eight pounds) of pure carbon is 139,398,869 heat units. The heat units of 1,000 feet of gas will be found on the basis of these figures to be equal to 57.25 pounds of carbon, or 67.97 pounds of coke, or 54.40 pounds of bituminous coal, or 58.40 pounds of anthracite coal. If Connellsville coke is worth $2.50 per ton, 1,000 cubic feet of Pittsburgh gas has a fuel value of 7.8 cents. If Pittsburgh coal is worth $1.25 per ton, the fuel value of 1,000 feet of Pittsburgh gas is 3¼ cents. One ton of Pittsburgh coal is theoretically equal to 36,764 cubic feet of Pittsburgh gas.

Professor Howard has applied calculations of the same sort as those above given to Findlay gas, and the following results are given:

One ton of Pittsburgh coal is theoretically equal to 31,085 cubic feet of Findlay gas. The heat units of the gas aggregate 228,461,113 to the 1,000 cubic feet. The theoretical value of 1,000 cubic feet of the gas is 3.9 cents, when Pittsburgh coal is worth $1.25.

In the preceding calculations, it will be observed that theoretical values only are discussed. The practical advantage in the use of gas is much greater than the figures above given would lead us to expect. In burning coal a large part of the possible heat is lost in various ways. In burning gas there is a much greater economy of heat possible.

Theoretically one pound of Pittsburgh coal is equal to eighteen and one-third feet of Pittsburgh gas, but it has been determined by carefully conducted experiment, that seven and one-half feet of gas are practically equal to one pound of coal. Findlay gas will give somewhat better results than this. Less than seven cubic feet of gas will do the work of one pound of Pittsburgh coal, or less than 14,000 cubic feet of gas are practically equal to one ton of Pittsburgh coal.

Trenton limestone gas is thus seen to be one of the most valuable fuels known to man. The reckless use and especially the wanton waste of it are little less than a crime against the state.

The gas is admirably adapted to domestic use, the only drawback being the small proportion of sulphuretted hydrogen that it contains. It answers a fair purpose for household and street illumination, but in these respects it leaves something to be desired. It reaches its highest adaptations in iron-working and in glass manufacture, and also in steam production. For lime-making and brick-burning, it is also excellently adapted. These points will be brought out in the subsequent accounts of these special interests.

It is obvious that where natural gas can be obtained as abundantly,

as certainly and at as little outlay as at Findlay, neither individuals nor corporations will be allowed to make a monopoly of it or gain any undue advantage from its general use.

The pioneer company that discovered the gas proceeded, as soon as practicable, to pipe the town and sell the product of their well to the citizens. The rates that they fixed were by no means exorbitant or unreasonable, considering the elements involved. When the Gas-Light and Coke Company that was engaged in the manufacture of artificial gas in the town had followed the lead of the Natural Gas Company, and had obtained a flow of gas equal to that of well No. 1, they proceeded at once to turn it into the pipes that had been laid for the artificial supply, and to sell it for light and heat, an unwelcome intrusion upon the field that the new company had mapped out for itself. The gas-light company found it necessary to greatly extend its lines, and, in fact, to lay an altogether new set, and presently the town was piped by both companies, all the main streets carrying double lines. A measure of competition was secured by this arrangement, but one company was financially weak, and growing weaker, while the other was strong and gathering strength all the time. The end is easy to be seen. The Natural Gas Company was absorbed by the Gas-Light and Coke Company, and the work of extending mains and drilling new wells went on rapidly on every side under a single control. The following rates for gas were established:

For cooking stoves	$1.00 per month.
For heating stoves	$1.50 per month.
For grates	$2.00 to $2.50 per month.
For house lights	15 to 30 cents.
For boilers	from $150 upwards per year.
For lime-kilns	$100 per year.

These rates would not elswhere be counted unreasonable, but it was apparent that the company would, if allowed to go on without check, ultimately secure large returns on its investments. Fortune gave to this company the Karg well whose volume was many times that of all the earlier wells combined.

The cry of monopoly was raised, and complaint was made as to the established rates. The demand began to be heard that the city government should drill wells and itself undertake the supply.

It was finally brought about, by act of the Legislature, that the question of bonding the town for $60,000, to be used in drilling wells and in supplying gas to the citizens, should be submitted to the vote of the people. This election was forthwith ordered and the result was what could be expected under the circumstances. The proposition was carried by a very large majority and the city council entered upon its

new duties. The Gas-Light Company undertaking to defend what it counted its rights by appeals to the courts, found no ground on which it could make its resistance effective, and a third line of gas pipes was laid through the principal streets of the city. After the streets were piped in part, the work of drilling wells was begun. The first city well was located about 1,000 feet from the great Karg well. The expectation seemed to be that it would share the flow of its wonderful neighbor, but this did not prove true. The well was of quite a common-place character. The well was completed about the middle of November, 1886. Its record was normal in most respects. It found the Trenton limestone at 1,108 feet, or 338 feet below tide. The rock where first struck was dark and porous. In fact, it looked as if it had been already drained of its stores. The well was carried to 1,176 feet in depth, and the gas supply was decidedly weak. A torpedo was introduced, the first to be used in a Findlay gas-well, and the flow was greatly improved thereby. The well was measured on November 27, and its daily yield was found to be 1,179,619 cubic feet per day. This well was, however, large enough to meet all immediate demands of the city service. For three days the whole plant was dependent on it, and the pressure was reduced but few pounds thereby.

The second well had better fortune. The effort was made to so locate it between proved wells that failure should be impossible. The effect was successful to the extent of securing an excellent well. This well was also torpedoed, a sixty-quart shot being used in it with good effect. The open pressure in the three-inch pipe was reported by the manager to be fourteen and one-half pounds. This would show the yield of the well to be 5,557,830 cubic feet per day. The city also bought an excellent well that had been drilled on the north side of the town, the Cory well, and that was suitably situated for the supply of this district.

A fourth well has since been drilled by the city in East Findlay. Its volume is small.

The city supply was now far in excess of the largest possible demands. The schedule of prices fixed by the council was in substance made by dividing the old rates by two. In fact, the new rates were less than half of those previously in force. The new rates were as follows:

Cooking stoves	50	cents per month.
Heating stoves, one	50	" "
" three	30	" "
For two gas jets (light)	10	" "
For eight gas jets	30	" "

The Gas-Light Company, in its turn, divided the new schedule by two, as its own schedule had been previously halved. But the end was

not yet reached. When the city rates were brought down to those of the company, the latter promptly made a new reduction to 15 cents per stove. To this point again, the city followed and the company was proposing the new rate of 5 cents per stove. With the reduction already effected the cost of fuel and light had virtually disappeared from the householder's expenses in this favored town. All the heat required for a cooking stove for a year could be got for $1.80, and there were very likely discounts from this amount.

The strife between the company and municipal corporation involved some interesting and important questions in the science of government. The company was taxed to raise funds with which its own business was to be assailed and broken down. Fortunately, under the wonderful tide of prosperity which has visited Findlay, the danger has been averted, and the questions in dispute have been brought to an end by the prospective sale of the gas company's plant to the Council on an acceptable basis. The majority of the company seem satisfied that the course of the city has led to the general prosperity, and if they lose on the original investment, they have been able to recoup themselves in the great advance of city property of all sorts. It is easy to see, however, that a very different outcome might have resulted, and one in which grave injustice to the rights of individuals would have been done.

It is probable that rates will be advanced beyond the merely nominal charges which are now in force. The latter bear no relation to the real outlay, and the result will be, if they are maintained, to make the light and heat used by individuals of the community a charge in some way and to some extent upon the public treasury, an application of practical communism for which we are scarcely prepared.

The Growth of Findlay.

The development of manufacturing industries at Findlay, based on the utilization of its new found fuel, and the consequent expansion and increase of the town, must be briefly sketched, but no exhaustive account will be here undertaken.

When natural gas was discovered at Findlay, the corporation contained four square miles, and within these limits less than 4,500 people were living. As the abundance of the gas supply and its staying quality were demonstrated, a slow growth began in the latter part of 1885, which increased steadily through 1886. Prices for real property were advancing at a reasonable rate with the new demand, and purchases were made on a moderate scale with reference to occupancy and use. Manufacturing plants were coming in, bringing considerable accessions to the population.

A large number of dwellings, mostly of the cheaper grade, were erected in 1885 and 1886, and were all occupied as soon as completed. The town was making a healthful and fairly rapid growth, and was gaining recognition as the center of gas production of the new field.

The Briggs Tool Works was the first important addition to the manufacturing enterprises of the town. Reference has already been made to the well drilled for this company. The works now employ seventy-five men in the manufacture of farming, mining and railroad tools, and many minor specialties. This company was the first to employ Findlay gas in welding iron and steel, a result which was accomplished on June 8, 1886. This is counted one of the great dates in later Findlay history, and its anniversary was celebrated with extraordinary display by the town in 1887. The location of the company here was decided by the gift of land, free fuel in the shape of a gas-well and other advantages.

The same company has recently added to its plant a rolling-mill, which will manufacture merchant iron for its own use and the general market. Its fuel will be derived from the company's well, which is ample, several times over, for the purpose. The upper vein of gas from the well has been suffered to burn without utilization most of the time since the well was drilled. When measured in 1886, the volume of this upper vein was found to be between 200,000 and 300,000 feet per day. This loss went on for more than a year.

The adaptation of natural gas to glass manufacture is perhaps the happiest in its long list of services. It involves the following items, viz., the lessened cost of fuel, which in fact disappears altogether in the new gas-fields, the reduction of labor in caring for the furnaces, the improved quality of the product, and lastly the life of the furnaces. The last item is one of the most important. This line of manufacture was therefore sure of being attracted to Findlay at an early day. Three important glass-factories have been already established here, and are in most successful operation. Four additional ones are now being added to the list.

The first three are as follows:

The Findlay Window Glass Company, located in May, 1886, in operation September, 1886.

The Columbia Glass Works, located in July, 1886, in operation January, 1887.

The Gas City Works of J. T. Wilcox & Co., located in October, 1886, in operation March, 1887.

The first of these companies consists of the junior members of a Bellaire glass company. Their original plant consists of an eight-pot furnace, but after a year of very successful business, they have recently

more than doubled their production by adding a ten-pot furnace. Sylvania sand and Fostoria lime have been used with entire satisfaction in the manufacture of window-glass. The quality of the product is unsurpassed.

The second company came from Pittsburgh. It started with a thirteen-pot furnace, and employed 140 men. It has increased its capacity and employs half as many more men. The company manufactures table glass-ware of excellent quality, using sand obtained in Hancock county, Maryland. The gas-well drilled for these three companies, and commonly known as the Columbia well, was estimated to produce 5,000,000 cubic feet per day, when completed. It reached the Trenton at 1,120 feet, or approximately at 340 feet below tide. It obtained its main supply of gas from 23 feet below the surface of the rock. The gas is perfectly adapted in every respect to this line of manufactures.

The third company has recently been reorganized. It has an eight-pot furnace—makes window-glass, and uses Toledo sand (Sylvania and Monclova.)

A fourth glass-factory is nearly completed on the Whitely farm, to the southeast of the town. Three gas-wells have been drilled on the property. Their production is small, but ample for all the purposes required. The company will have eight pots in operation in the fall of 1887.

North of town, on the Heck farm, where a gas-well of large volume has been drilled, another glass-factory has been begun by Hirsh, Ely & Co. It will have a ten-pot furnace in operation before January, 1887. The capacity of the Findlay field at this last named date will exceed sixty pots.

Another enterprise in the same general line, is the Lantern Works that has been established here by parties from Bellaire. The company has erected a substantial and excellent building, and has added to the town an industry of great value.

Iron-working has been begun on a still larger scale, so far as the prospective cost of the plants and the number of men to be employed is concerned. The Briggs Works, with its recently established rolling-mill, has already been briefly described.

The Findlay Iron and Steel Company, which is also known as the Carrothers Rolling-Mill, is well located on the northeastern side of the town. The machinery has been brought in part from works formerly established in Cincinnati, but a large proportion of the stock of the company has been subscribed in Findlay.

The Lagrange Rolling-Mill and Nail-Works, which is now in process

of removal from Lagrange, Mo., is located on the southwestern side of the town. This is counted the largest establishment that has been attracted to Findlay by the new advantages that the town can offer. Its working force is put down as 800 men. The machine shop of the company has already been built and equipped.

Near to it, in the same addition to the town, is located the Ohio Coil and Cable Chain Works, which is at this time about ready to begin operations. This company has moved its works from Cleveland for the sake of the advantage of natural gas, to be had here without money and without price.

The Heck farm, with its great gas-well, has been already named. Near the glass-works, now being built on this farm, an iron-working plant is also in process of erection. It belongs to the Wetherell Wire Nail Company. It makes a very valuable addition to the growing industries of Findlay. At Stuartsville, four and a half miles due north of the court house, at the crossing of the Nickel Plate and the Toledo, Columbus and Southern railroads, a very important iron-working plant has been located. Twenty acres of land and free gas for five years, have been given to it. It ensures a manufacturing village at this point, Excellent gas-wells have been found in this vicinity, and are already available for the largest possible demand.

While glass-manufacture and the various forms of iron-working are the most important industries attracted to Findlay by the advantages which it has lately been able to offer, they are not the only ones.

Furniture manufacturing, wood-working, lime-burning and the manufacture of brick on the large scale, have also recently been established here, and all these are now in successful operation. Gas has been found to be the best possible fuel for brick-making. It gives a perfectly even and uniform product. The works for manufacturing pressed brick are now turning out an admirable article.

Lime-burning by natural gas is carried on by Mr. D. Barnd in kilns of the old pattern. His kilns are to the south of town and a little west. The quality of his lime has never been more acceptable. Mr. C. B. Hall has two patent or draw kilns on the same side of the town, and he also reports entirely satisfactory results. For the present the extraordinary growth of the town is taking up the entire production of the kilns. Both parties are burning the Waterlime formation, which is a dolomite of the usual excellent character of northern Ohio.

It is impossible to learn at the present time what amount of capital or what number of people has been brought into the town within the last year. Both accounts would involve quite large figures. The orderly growth of 1886, which has been hastily sketched on a preceding page,

came to an abrupt termination with that year. The opening weeks of 1887 witnessed the breaking out of a speculative excitement of extraordinary intensity. The entire community was affected by it, nor was it confined even to the limits of the state. It found the city of Findlay, as already stated, with territorial limits of four square miles. It left it with twenty-four square miles on paper, the entire township having been brought into the city. A considerable part of the farm lands adjoining the town has already been broken up into "additions", and many of the latter are already divided into town lots. Streets are graded and shade-trees set. Several of the manufacturing establishments that have been described on a preceding page are located in these additions, from two to three miles distant from the court-house.

Within the present limits of the city it is estimated that seven hundred dwellings have already been built during 1887, and as many more are under contract to be completed before the end of the year. It is claimed that twice as many new houses would be occupied this year, if they could be provided.

A local census taken in the spring of 1887, showed 10,221 persons residing within the four square miles that constituted the old town. This number has already been largely increased within these limits, and still further, by the establishment of the several additions above named. Estimates vary between 13,000 and 18,000 as to the number in Findlay in August, 1887.

Under the excitement of the first three months of 1887, the prices of real estate advanced to very extravagant figures. At the end of that time purchasers had disappeared and sales were thus arrested. A large number of important enterprises have, however, been established in the town since that date, attracted by grants of land, the offer of free fuel, and in some cases by stock subscriptions, aided by great effort and activity on the part of the Chamber of Commerce.

One class of the population has reaped a rich harvest from the increase of prices of real estate, viz., the farmers who held the outlying lands around Findlay. They have received for their lands twice, three times, or even five times the prices at which they held them in 1886. Most of them were sagacious enough to take the tide as it rose. Comparatively little of the farming land of Findlay township remains in the hands of its old owners.

Street railroads are being built on quite a large scale in the city, and the town has voted to bond itself for water-works. An adequate and satisfactory water supply is even more of a desideratum in Findlay than in most other Ohio towns of similar situation. On the south side of the town, flowing wells of good quality are struck, but the center is

losing the drift-water on which it has heretofore partially relied. This loss is gain, however, so far as the health of the people is concerned, as the character of this supply was beyond question dangerous, the drift being shallow and the town unsewered. The Blanchard River is the source to which Findlay seems, of necessity, to look for its future supply, but on the great scale on which the city is now platted, the entire volume of the river will be inadequate. The problem is undeniably a difficult one.

The wells drilled since the date above given (April, 1886,) must be divided into two groups, viz., the gas-wells proper and the oil-wells. Of the latter there are 100 already completed. A few of the important ones will be enumerated on a succeeding page, but a list is not called for at this time.

Of gas-wells, counting in those already reported, there are in the county at the present date (August, 1887,) twenty-five to thirty that deserve the name. The more important additions to the previous list, page 132, are the following, viz.: (The list is not complete).

	Depth at which Trenton is struck.	Trenton below tide.	Depth of well.
Columbia	1,120	338	1,172
City, No. 1	1,108	338	1,196
City, No. 2	1,124	344 ?	1,173
Funk			
Thorntree	1,142	340 ?	1,235
Heck			1,135
Crossley	1,145	325 ?	
Stuartsville			
Barnd	1,141		
Van Buren, Kagy	1,087	332	1,113
Weisel	1,102	347	1,138
Ballard	1,213	415 ?	1,248
Houcktown	1,180		1,204
Fostoria—City, No. 1	1,141	380 ?	1,169
" " 3	1,134	370 ?	1,164

To this list can be added the following, which are all reported as small producers:

City, No. 4.
Carnahan, Nos. 1, 2, 3.
Fostoria, No. 2 (carries oil).
Rambo.
Bright.
Vanlue.
Mt. Blanchard wells.

The Bigelow, Baker, Ohmer and Davis wells have not been reported to the Survey, and no opportunity has been found for examining them.

These gas-wells are confined to those areas of the county in which the Niagara limestone makes the surface rock. It will be remembered that the Niagara and Lower Helderberg (Waterlime) formations divide between themselves the entire surface of the county. The gas and oil of the county follow very closely these geological boundaries, the gas belonging to the outcrops of the former, and the oil to the areas covered by the latter. The Niagara areas of course indicate the higher levels of the underlying Trenton.

A few of the gas-wells are found on the edge of the Waterlime, as for example, the Karg and the other wells adjacent to it, but the Niagara is in all these cases near at hand. A single well, viz., the Motter well, in Orange township, located on Waterlime territory, has produced a moderate flow of gas, viz., 175,000 cubic feet per day, but it is probable that its life would be short. Salt-water or oil would soon overrun it. The Trenton limestone was 424 feet below tide, giving it an advantage over adjacent territory.

The Findlay break appears to extend in a northerly direction from Findlay. It is not certain that it holds a straight course, but its general bearing is established. There are no indications whatever of the important flexure that has been described under this name further than those furnished by the fact that the Niagara limestone makes the surface rock on one side and the Waterlime on the other. The surface itself is approximately level. The wells that are drilled along this territory furnish, however, unmistakable evidence of the extension of the geological conditions found at Findlay.

The gas and oil districts are separated by a sharp line. On one side of a road, for example, gas is to be looked for, and on the other, oil. All the dry gas comes from the east side of the break, and all the important production of oil from the west side.

It seems probable that a belt of oil-territory will be found along the western margin of the break. The North Baltimore oil-field, which is the most remarkable section of the new production, is located on this

margin of the break, though the structure is less simple at that point than further south or north.

The main production of dry gas in Hancock county is thus far confined to the following townships, in whole or in part, viz., Findlay, Allen, Cass, Marion, Jackson and Washington. Amanda and Delaware have also furnished smaller amounts of gas.

The Trenton limestone loses character as an oil or gas-rock as it is followed to the east or south.

At Arcadia it gives the following results to chemical analysis, viz.:

Carbonate of lime	84.23
Carbonate of magnesia	5.44
Insoluble matter	8.56

So far as examinations of this point have now extended, the Trenton limestone is nowhere a good oil or gas-rock where it has a composition like this. The loss of character in the limestone, as it is followed southwards, no doubt explains its unproductiveness in the central southern townships. Two lines of conditions essential to large production in the Findlay field have now come into view. (1). The Trenton limestone must have a certain chemical composition, viz., it must be a dolomite and approximately pure. (2). The limestone must occupy a certain absolute level, viz., it must not fall more than 500 feet below tide, or else it will, in this field, be flooded with salt-water.

The eastern and central southern townships are, to a greater or less extent, condemned under the first count. Moderate gas-wells and dry holes are in order here. Under the second count Pleasant, Portage, Blanchard, and parts of Liberty, Union and Orange are condemned. This territory falls below the dead line. Ridges will no doubt be developed within these areas, if large exploration continues, where more or less production can be obtained. So far as examined, the composition and grain of the rock are suitable to production throughout the western side of the county. It is the depth of the Trenton limestone only that proves fatal to it as an oil-rock here.

The Findlay gas-field has recently received a very important addition to the southeast of Findlay, by the bringing in of the Ballard and later of the Houcktown well. The first is situated three and one-half miles south and a little east of Findlay, in Section five, Jackson township. It found the Trenton at 1,215 feet below the surface, or a little more than 400 feet below tide. It has a higher closed pressure than the Findlay wells, the gauge standing at 445 pounds. Such a result is to be looked for and explained by reason of the greater depth of the Trenton limestone, viz., 1,215 feet, against 1,118 in the Karg, for example. A

measurement taken at the end of 200 feet of three-inch pipe, with sixty-five pounds of back pressure on the well, showed its production to be 5,600,000 feet. Under more favorable conditions for its flow to escape it would make a considerable addition to these figures. It is a well of much vigor and promise.

The Houcktown well is also reported as showing great force in good degree. It is about eight miles south and a little east of Findlay, being located in Sec. 21, Jackson township. It reached the Trenton limestone at 1,180 feet, and found a little salt-water before it was finished at 1,204 feet.

North of Findlay, not far from the line of the break, is a series of noble wells. Among these may be named the Heck, Crosley, Stuartsville and Van Buren wells. The Heck well has been estimated at 8,000,000 cubic feet of gas per day. It is not known to have been measured. The Crosley well has at least as large a production as the Heck in the judgment of those who have compared the two.

The largest gas-well of the state, up to the present date, was brought in near Van Buren, Allen township, during October, 1886. It is located in the N. E. $\frac{1}{4}$ of the S. E. $\frac{1}{4}$ of Sec. 12, on the Kagy farm. It was drilled by Conroy and Johnson, and was by them sold to the Northwestern Ohio Company.

The record of the well is as follows: The drift was eighteen feet thick. The casing stands at 285 feet in the Medina shale. The Niagara shale was twelve to fifteen feet thick, and fifty or more feet of the Clinton limestone was recognized below it. The Trenton was struck at 1,087 feet, or 332 feet below tide-water. The well was finished at 1,113 feet. No gas was found at the usual shale horizons, but the moment the Trenton was touched, a moderate flow appeared. The gas strengthened as the drill went down, until at a depth of twenty-eight feet in the Trenton, it became irresistible, and the only thing to do was to get out of the way of the furious column.

A measurement was executed on November 22, 1886. The open pressure was found to be five and one-half to six and one-half pounds at the end of fifty feet of horizontal casing connected with the well-head by an elbow.

Adopting six pounds as a fair average, the yield of the well was found to be, according to the specific gravity of the gas employed in the tables, 14,984,352 cubic feet for twenty-four hours. The temperature of the gas was 35° F.

On November 27 the well was tubed with four-inch pipe and packed, and was again measured. In the four-inch pipe an open pressure of twenty and one-half pounds was found, against fifteen pounds in the

Karg well under like conditions. The yield from the four-inch pipe is thus seen to be by calculation, 12,614,400 cubic feet per day. The reduction effected by bringing the gas through the four-inch tubing is 2,370,000 cubic feet per day.

By the corrected calculation for the specific gravity of the gas, both sets of figures are somewhat increased.

The area of gas territory in Hancock county cannot be measured with accuracy at present. There are not less than 100 square miles for which this name is generally claimed. To this may be added, 25 to 50 miles, for which an argument can be made. The really choice territory is much less extended, but it still includes several scores of square miles in five townships.

The Findlay Oil-Field.

The early tests of the Trenton limestone at Findlay showed the presence of oil at certain levels in the producing rock. The Adams well, which is counted No. 4 in the order of drilling, began its production with dry gas, but in the course of a few weeks oil appeared with the gas. The amount soon increased, until a separator was necessary. During the fall of 1885 the well was producing four to five barrels of oil per day, together with its one and one-fourth million cubic feet of gas. The Lima Road well, and also the Putnam Street well showed the presence of oil in considerable quantity. It was soon recognized that the gas-rock was dipping sharply to the westward from about the line of Main street, and that when it was struck at a level lower than 400 feet, it was likely to contain oil rather than gas. The first well to be drilled expressly for the purpose of reaching the oil, was the Matthias well, No. 1, the record of which has already been given. The result attested the sagacity of the company that located it. It proved to be a flowing oil-well, with a steady production of thirty to thirty-five barrels per day. This may be taken as the initial date of the Findlay oil-field. The well was finished in November, 1885, but no further drilling in this interest was done until 1886. After the fashion of oil-fields, new wells were located as close as possible to this successful one. Those nearest repeated the experience of the first well. The price of oil was forty cents per barrel, and a daily flow of thirty barrels was therefore counted a fair return. The field, however, soon began to reveal its lines. Barren rock was found at some points and salt-water at more. The territory to the southwest of the town proved unproductive, and a limit was thus laid down in this direction.

This was the direction to which all the imported traditions of the Pennsylvania field pointed as to the line of promise, and it was only

when the oil-rock was found charged with salt-water, ready to fill the well as soon as its level was struck, that the search along this line was abandoned. The search to the northeastward was of course cut off by the upper terrace of the Findlay monocline, which was gas territory by way of excellence, and the southeast was known to be gas territory, if anything. From three of the quadrants of the circle at the center of which he stood, the driller was therefore cut off in his search for oil, and his only lines of advance were between west and north. Deep-set casings, Trenton below the dead line, and consequent floods of salt-water were soon reported from the northwest, and the productive field was still further narrowed down. Its boundaries are now fairly distinct, and the Findlay oil-field can be defined as consisting of a low ridge or terrace of Trenton limestone, approximately horizontal, about 1,250 feet deep, about two miles wide in a north and south direction, and less than five miles long in an east and west line, extending west and a trifle north from the court-house in Findlay. The entire productive territory is virtually included in Liberty township, and in the following named sections of this township, in whole or in part, viz.: Nos. 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 20, 21, 22, 23. Sections 11, 12, 13, 14 of Findlay township must be added to complete the account. Sections 16 and 17 of Liberty have furnished the great wells. The territory is, however, spotted, and small wells are found surrounded by large producers. There is a possible outlet to the northwest that may add a little more productive territory.

Like all the other Trenton limestone oil-fields, the Findlay field has been held in check by the small and steadily lessening price that has been paid for its production. Whatever development is to be recorded has gone forward under the most discouraging circumstances. The great corporation that is taking care of the oil has found it necessary to repress and finally to arrest production, if not by a price that has dropped by rapidly following stages to insignificance, by an enforced agreement on the part of the operators to suspend the drill, to abjure the torpedo, and to lock in all the wells that can be safely treated in this way; the agreement being made under the distinct intimation that the care of the oil would be given up unless its production could be curtailed.

The facts pertaining to this subject will be more fully stated under the discussion of the Lima oil-field, which is to follow on a succeeding page. The general statements already made, are, however, to be borne in mind in considering the statistics of the field, which will be briefly given at this point.

Development of the Field.

As already shown, the real proving of the field began in the spring of 1886. The first well of fairly promising volume was reached in October of that year.

By September, 1886, twenty wells had been drilled that produced more or less oil. The daily production was counted a little more than 400 barrels.

In October there were twenty-eight producing wells, with a daily production of 726 barrels.

In November the production was brought up to 1,300 barrels. The new wells of this month, nine in number, added 600 barrels to the previous figures. There were now counted forty wells in the field.

The December record showed a considerable expansion. The number of producing wells was now fifty-five, and the daily yield was counted nearly 2,000 barrels.

By February 1, 1887, there were sixty-seven producing wells, with a daily production of 3,000 barrels.

By June 1st, there were 100 wells in the field (97), with a daily capacity (production is no longer quoted) of 6,000 barrels, and the work of drilling new wells was substantially abandoned. The sixteen new wells of May were reported as producing 1,355 barrels, an average of eighty-four barrels. By this figure the rapidly expanding promise of the field is seen.

A very brief review of the order of the development will be added at this point.

The summer of 1886 was a day of small things for the Findlay oil-field. None of the wells exceeded seventy barrels for their initial flow, except in a few cases, where the effects of the torpedo would bring the rate up to higher figures for a day or two. To counterbalance this small volume, however, there was gas enough in many of the wells to raise the oil, or in case the quantity was insufficient to make the wells flow, it was still enough to contribute largely or entirely to the pumping. In this respect the Findlay field was decidedly in advance of the wells of equal production in Lima.

About the middle of October, however, a well was brought in on the Cramer farm, N. W. $\frac{1}{4}$, Sec. 22, Findlay township, two miles due west of the court-house, which put a different face on the field. This well delivered through the casing into the tank, 150 barrels of oil on the first day after it was completed. At the end of five weeks it was still flowing 100 barrels per day.

Its record in this connection is an interesting one. Its elevation

above tide is 789 feet. The depth of the Trenton is 1,249 feet, and the upper surface is thus seen to be 460 feet below tide. But this elevation is greater by five to ten feet than that of the same stratum in all of the wells to the east of it.

It shares its elevation with the wells on the Kutz and Schoonover farms, immediately adjacent. The Kutz well proved to be even a better producer than the Cramer, starting out at a 250-barrel rate.

The levels of the limestone in a few of the wells that first gave character to the oil-field are appended:

	Trenton limestone below tide.
In section 12, Findlay township—	
Howard well	467
Bolton well	479
Corothers well	489
The descent of the limestone is to the west.	
In section 13, Findlay township—	
Karg well, No. 2	468
Bookmiller well	472
Matthias well, No. 1	481
" No. 2	470
Wade well, No. 1	474
" No. 2	467
Bruner well	491
In section 14, Findlay township—	
Burkey well	465
Alge well, No. 1	471
" No. 2	473
Whistleman well	473
In section 22, Liberty township—	
Cramer well	460
Kutz well	460
Schoonover well	459

The influence of the elevation of the oil-rock on its production, is still further illustrated in the behavior of the two Wade wells, S. W. ¼, Sec. 13, Findlay township.

Well No. 1 found the Trenton 474 feet below tide. It produced about six barrels of oil, with one to six barrels of salt-water.

Well No. 2, situated a few rods to the north, had an advantage of seven feet in the level of the oil-rock. Its best flow was sixty barrels of oil. During the first two months it produced about forty barrels for a daily average, falling away slowly to a twenty-five-barrel rate. This well had not been shot when the record was obtained.

The effect of the torpedo is quite marked in the Findlay field. A well drilled in dry has been made into a 200-barrel producer, for its first day's flow, by a heavy shot.

The most significant example, however, is furnished in the well of Penzer & Co., on the D. J. Cory farm, Sec. 16. Liberty township. This well was drilled in during February, 1887, and took a very moderate rate of twenty-five barrels daily production. It was shot with 80 quarts March 14, and was thereby converted into one of the great wells of the entire territory. During the first week thereafter, it had put more than 5,000 barrels of oil into the tank, and had been shut in a part of the time. There is no doubt that it would have produced 1,500 barrels per day, if unobstructed, in the first few days after it was shot. At the end of two months it was producing 800 barrels per day, and August 1st, 1887, it was producing 350 barrels per day. Its total production exceeds 50,000 barrels, and perhaps will already reach 60,000 barrels. This is the largest well of the Findlay field proper, and ranks among a half-dozen of the great wells that the Trenton limestone has thus far furnished. The well, on the adjoining section, struck a still higher initial rate, but the well was drilled too deep and carries a little salt-water.

Production of nearly this rate has been also reached by the well on the Cyrus Grubb farm, that flowed forty barrels per hour for the first day. It was finished early in March, 1887.

The general characteristics of the Findlay oil pool can be made out from the statements already given. It is obvious that there are great possibilities here when the time comes for the proper recognition and development of this immense stock of power.

Findlay oil has been taken care of, i. e., transported from the wells, stored and purchased by the Buckeye Pipe Line Company, which is a branch of the Standard Oil Company, and to a small extent by the Findlay Pipe Line and Refining Company. This last-named company has a tank of 26,000 barrels capacity at its works. Its operations in refining the oil will be described in another connection. The Buckeye Pipe Line Company has already put up 21 tanks, with a capacity of 30,000 to 36,000 barrels each, and is going forward with the work of storing the oil at very large expense.

Conclusion.

This fragmentary and incomplete account of the Findlay field must be brought to an end. Much remains to be told concerning the outcome of the remarkable discovery of November, 1884, but the essential features of the geology and the production of the new field have now been set forth.

One question remains to be answered concerning it, a question that is first to be asked by every intelligent observer of the surprising facts that appear. It is this, viz., how long will the supply last?

As to the oil-field no extended discussion is required. The Trenton reservoir shows fair staying quality, but there is nothing whatever upon which to base a claim that its flowing wells will flow forever or that its pumping wells will respond to the pump indefinitely. The greatest oil-well in the field falls in four and one-half months from 1,500 barrels to 350 barrels in its daily production, and we have nothing but praise for its persistency, as shown by its slow rate of decrease.

C. S. Wade's well, No. 2, Sec 13, Findlay township, already referred to, began its production in September, 1886, with sixty barrels. It soon fell to forty and then to twenty-five barrels, and is now, at the end of eleven months, flowing eighteen barrels. These are favorable examples of the behavior of the Findlay oil-field. In other words, the field follows the laws of all oil-fields in its gradual reduction of pressure and production.

Will the duration of the gas-supply of Findlay, in like manner, follow the law of other gas-fields, or will it prove a unique and solitary exception to all previous experience?

There is nothing whatever to support this last-named alternative. The ardent wishes of the favored communities that have secured the new fuel, that their supply shall be perpetual, do not go far to prove that it will be perpetual. The so-called "theories" that are advanced in support of such a view, are utterly crude and baseless. Findlay gas will obey the law, *is obeying the law*, of all high-pressure gas that has ever been discovered. It is a stored product. The amount of it is measurable. Every foot withdrawn from the reservoir leaves the ultimate stock less. Several of the wells already in use establish the fact of an appreciable decline in volume.

The structure of Findlay is exceptionally favorable to gas accumulation, as it appears. Its supply is vast and of priceless value, but far too much has been already lost through indifference and ignorance or wasted in vain display. A halt should be called and a new order at once established and enforced.

For the illumination of the city, for example, more than 200 torches are now employed in place of gas-jets. The great expansion of the city limits will soon increase this number several fold. Each torch is estimated to burn per hour 50 to 100 feet of gas, or 1,200 to 2,400 feet per day. Private grounds in like manner are provided in many cases with these wasteful floods of light. The street lights at present are left burning in many, if not in most instances, all day. This is simple vandalism, as wanton a waste of accumulated wealth as that in which the term originated.

Findlay is to be congratulated on the score or more of important

manufactories which its advantages and its enterprise have already won for it. Thus far it has gained more than all the rest of the gas-field in Ohio and Indiana combined. There is a richly remunerative use before it for every foot of gas that its great reservoir contains. It has done enough already to advertise its great fortune and its great possibilities. It would be the height of folly for the town to spend so much in the splendor of its invitations that it should materially reduce thereby the amount of its substantial attractions.

THE BOWLING GREEN FIELD.

This field comes second in order of development, and was for some time second in order of importance in the supply of gas from the new horizon. After the discovery of high-pressure gas in Findlay, in November, 1884, a wide-spread interest and curiosity was aroused in the adjacent towns of northern Ohio as to their own possibilities. In all of the earlier discussions that followed the discovery of Findlay gas, the Cincinnati axis was made to take a prominent place. A more or less distinct fold or anticlinal was supposed, on geological authority, to extend across this portion of the state, upon the crown of which Findlay was now thought to be located. It was inferred that other productive localities would be found along the northward extension of this axis. It has already been shown that this great feature in our geology does not correspond well to the popular idea of an anticlinal, but the facts bearing upon this point were not then available. Speculations as to the extension of this axis had something to do with the location of some of the earlier wells to the north of Findlay, and possibly here.

Like Findlay, Bowling Green is underlain with the Niagara limestone. It is twenty-four miles due north of Findlay. Its surface has even less relief than the region southward. A limestone ridge traverses the town and the rock is everywhere very shallow. The altitude of the track at the station of the Toledo and Southern railroad, is 701 feet above tide-water, or about eighty feet below the general level at Findlay. This is as high a point as there is in the neighborhood. The average elevation is fifteen to twenty feet less than this.

The Bowling Green Natural Gas Company was organized by a number of the most enterprising and public-spirited citizens, in January, 1885. Brownyar & Martin took the contract for drilling the trial well, and work was begun on February 4, 1885. The record of the descent agreed in almost every respect with the record of the Findlay

well. Samples of the drillings were saved with great care by C. W. Evers, Esq., and were turned over by him to the service of the Survey. They proved very valuable, and in connection with the samples of the first Findlay well, collected by Mr. C. J. Eckels, they served to furnish a new and for the first time an authentic record of the underground geology of this portion of the state. The Utica shale was dislodged here in quite large fragments, immediately above the Trenton or gas-rock, by the explosion of a torpedo, and it so chanced that the fragments were charged with the most truly characteristic fossil of this wide-spread stratum, viz., the minute brachiopod shell, *Leptobolus insignis*, *Hall.*

The record of the well is as follows:

Upper limestones	305 feet.
Shale, red Shale, gray Shale, brown	790 "
Gas-rock, struck at	1095 "

Interpreted by the drillings saved by Mr. Evers, the record would take the shape indicated below, some of the boundaries being, however, indefinite:

Niagara limestone	230 feet.
Niagara shale (15 to 30 feet)	15 "
Clinton group	60 "
Medina shale (30 to 50 feet)	50 "
Hudson River shale	480 "
Utica shale	250 "
Trenton limestone, at	1095 "

This record is illustrated in the preceding plate, page 112.

The Niagara shale was first found, for this district, in characteristic phase in this well. It is easily recognizable in all of the wells that have been since drilled. It is a water-bearing horizon, as it also is in its outcrops. The water yielded by it in the wells is very high in mineral matter, being more like a bittern than a brine. This is seen in the following analysis made for the Survey of water derived from well No. 2: (*Lord.*)

Specific Gravity, 1.117. *Parts in* 1000:

Chloride of sodium	83.30
" " calcium	60.05
" " magnesium	15.96
Sulphate of lime	1.04

Traces of sulphuretted hydrogen.

Dr. Sterry Hunt has called attention to the peculiar character of these Lower Silurian brines. *Chem. Essays*,, p. 158.

The composition of the Clinton limestone, as found at 210 feet, and again at 260 feet, is shown in the following analyses, viz.: *Lord.*

	210′	260′
Carbonate of lime	49.19	51.62
Carbonate of magnesia	40.31	44.08
Insoluble residue, silica, etc	7.76	0.97

It was expected that the Clinton would agreee more closely with the formation in its outcrops, in which case it would have shown 80 per cent. carbonate of lime. On the contrary, it proves to be a dolomite, the last example being remarkably pure. It agrees with the best phases of the Niagara in this respect.

Gas, peculiarly rank with sulphuretted hydrogen, is yielded from this horizon. It is so offensive sometimes as to be rejected from the mains.

At 315 feet, dark-brown shales were reported. They lie near the boundary of the Clinton and Medina formations. At 330 feet, in the upper Medina, a pocket of gas of great force and volume was found. The gas, when lighted, blazed thirty feet above the casing, but it exhausted itself within sixty hours after it was struck. It may prove that we have here a thin bed of sandstone of the Medina type. Facts are not at hand by which this question can be settled now. Gas is frequently found at this horizon. The red phase of the Medina shale appeared at 350 feet. At about 410 feet, the characteristic light-colored shales of the Hudson River group, with their fossiliferous bands, were found; they continued for about 450 feet, but the lower boundary is not sharp. The Utica formation is represented by about 250 feet of homogeneous shale, dark-brown in color, and yielding easily to the drill. The composition of the formation at 975 feet is shown in the following analysis made for the survey: (*Lord.*)

Carbonate of lime	11.87
Carbonate of magnesia	6.88
Insoluble residue, silica and silicates	68.32

This is not unlike many beds of the Cincinnati shales in compo sition, but it is much darker in color than the last-named beds.

The Trenton limestone, or the gas-rock, is a light-colored, crystalline, hard and massive rock. Its composition is shown in the following analyses, the first one being taken from 1,096 feet, (the gas rock proper), and the second from 1,190 feet. The results are as follows: (*Lord.*)

	1	2
Carbonate of lime	51.78	88.64
Carbonate of magnesia	36.80	6.77
Insoluble residue, silica and silicates	4.89	2.15

The close agreement between the productive phases of the Trenton limestone, at various points in the field, has already been noted. The oil and gas-rock is seen to be everywhere a magnesian limestone or dolomite. Its upper portion is very porous, as is shown in fragments brought up by explosion.

The Bowling Green well obtained but a small supply of gas in the lower rock. In fact, the well appeared to be nearly a failure. The drilling was, accordingly, carried downward for about two hundred feet into the Trenton limestone, but without any increase whatever in the amount of gas. Recourse was then had to the torpedo. Three hundred pounds of rack-rock were exploded in the Trenton limestone at the productive horizon on March 21, 1885, and what was then counted a fine flow of gas was thereby secured. The gas was at once utilized for power in the flouring-mill, located near, and arrangements were begun for introducing it as household light and fuel throughout the town. This first well remains a serviceable and steady source of supply to the town, though its production is not large. No opportunity has been found to measure its flow. In 1885, the pressure, as shown in the steam-gauge, after the well had been closed ten minutes, was sixty-two pounds per square inch.

During the first year that followed the opening of the field, five other wells were put down to the Trenton limestone by the Bowling Green Company. The second followed close upon the completion of the first well, but it yielded only a small amount of gas, and no improvement was made by torpedoing it. Salt-water invaded it in considerable quantity, and finally the well was filled up for several hundred feet, only the surface veins of gas being utilized. But little account is made of it at present.

Wells No. 3 and No. 4 are also small, and their supply of gas would scarcely be missed from the mains at the present time. They are principally valued for reducing the friction in the pipes of the larger but more distant supply.

Well No. 5 is of the same force and value as No. 1, or, perhaps, it has a larger outflow. Of the first five wells, the first and the last have proved the main source of reliance to the company.

In January, 1886, there were dependent upon the gas mains in Bowling Green, 153 stoves, 1 furnace, and 134 lights. Several large buildings, as churches, were included among the buildings warmed and lighted. In severe weather, the supply was found inadequate. The combined production of the wells did not exceed 150,000 cubic feet, according to the calculations of the superintendent of the gas company, while 200,000 feet would be required to meet all demands.

This experience was somewhat discouraging to the company and the town, but it is now apparent that it has resulted to the ultimate advantage of both. If a large flow of gas had been struck in the town, it is obvious that private parties would have proceeded at once to sink wells, and, as in Findlay, a much larger supply of gas would be secured than could be used, while, at the same time, the reservoir would be more rapidly emptied. But these small and uncertain wells discouraged all private ventures, and fortunately the company had the courage to put down a sixth well a mile south of the town. (S. W. ¼, Sec. 30. Centre tp.) This well was drilled in February and March, 1886, reaching the gas-rock on March 13, at a depth of 1,086 feet. The well record agrees with the earlier records in all essential elements. There was a somewhat larger showing of red rock (Medina) in this well than in the others. It was finished at 1,152 feet. The gas in the other wells was all found at the surface of the Trenton limestone. In this, it continued to come into the well, and in constantly increasing volume, through the first ten feet of the Trenton. In this respect it agrees with the Findlay wells, and, in fact, belongs to the same order with them.

The amount of gas produced by this well was several times greater than that supplied by all the rest combined. It gave a new character to the entire supply. Until it was completed, the highest pressure shown in the mains was four or five ounces. The flow of the gas now need to be much restricted, so that the pressure should not exceed nine ounces. The gas from the new well was brought into the town by a five-inch main, buried below the frost line.

Its pressure at the well is over 400 pounds. It gains when shut in 100 pounds in thirty-five seconds. The gas of this well is counted more sulphurous than that of other wells in the line. It is thought to burn with a redder light. It will be remembered that in all the analyses made of Trenton limestone gas, almost absolute uniformity of composition was found. These claims for difference of character in the gas of the several wells must be taken with caution.

Wells Nos. 7 and 8 were drilled still further south, the latter being located in the N. W. ¼ Sec. 6, Portage township. This last-named well is the most vigorous that has been obtained by the company. Measured

August 20, 1887, its volume was found to be 924,480 cubic feet per day. The pressure through the open stop-cock of a two-inch pipe at the well-head, was six and one-half pounds. Its volume does not put it into the list of great wells, but its pressure rises with remarkable promptness. It gains when shut in:

100 pounds in five seconds.
150 " ten seconds.
190 " thirty seconds.
225 " sixty seconds.

These facts are of value because they show that the volume of a well cannot be safely connected with the rate of increase of pressure of the well, as has been heretofore held by many.

The closed pressure of a well has already been shown to be entirely without value as a guide to its production, and now even the rate of increase is proved to be equally unreliable as a means of determining the daily flow.

Mr. J. H. Ferry, the intelligent superintendent of the gas company, has observed a periodical fluctuation in the pressure of the gas in the wells each day. The maximum is reached at noon and at midnight; the minimum at morning, and again at evening. The range of difference is two and one-half pounds. These observations stand alone, and no explanation is offered.

The corporation of Bowling Green secured permission from the Legislature, at its last session, to bond itself to the extent of $25,000, to drill wells and to pipe the gas when found to the town, to be used free of charge, by manufacturers who locate their works here. The money has been already expended in part. Four wells have been drilled – one on the north part of the corporation limits, which proved too small a source of gas to be of value, one on the west side of the town, which is also of small value, and two others in Sec. 6, Portage township, 2½ miles south of the court-house. The last-named wells are fairly vigorous for the Bowling Green field. A six-inch line has been laid from them to the town, and an ample supply for manufacturing purposes is now available. More territory has been secured by both the gas company and the Trustees of the corporation in Portage township, and drilling is going forward at the present time.

In one of these city wells a pocket of gas was struck at a depth of 800 feet, which exceeded in force anything yet found in the field. The tools were thrown out of the well (800 feet deep), striking the top of the derrick as they rose, and knocking off the pulley block. Falling again,

the drill passed through a two-inch plank and a twelve-inch timber, and then sunk six feet into the ground. The blower exhausted itself in a few hours. The commissioners of the county have also drilled two wells on the Infirmary farm, one of which was dry, but the latter of which furnishes heat and light for the Infirmary.

Utilization of the Gas.

The Bowling Green Gas Company, in establishing its rates for light and fuel at first, followed the experience of some New York and Pennsylvania towns, the conditions of which agreed fairly well with those of their own town. They fixed the tariff at about two-thirds of the cost of the fuel displaced. The consumer had the advantage of the one-third reduction, and the wonderful convenience and saving of labor which the new fuel brings with it. These first established rates have been modified to some extent.

The rates for 1886–7 are as follows, discounts being allowed:

Cooking stoves	$2 50 per month.
Heating stoves	2 00–4 00 "

Gas-lights were counted at the opening of the field as follows:

1 light	30 cents per month.
2 lights	50 " "
3 "	65 " "
4 "	80 " "
5 "	100 " "

The rates of 1887–8 will be still further reduced.

During the last year there were 500 stoves dependent on the line. Provision is made for 1,000 stoves for the present year.

In addition to the domestic use of the gas in Bowling Green, it has been devoted, as in Findlay, to the production of lime. The Niagara limestone that comes to the surface here in long ridges is a very pure dolomite. Its composition, as sampled carefully from a section of ten feet in the Thurstin quarry near the railway station of the Toledo and Southern road, is as follows (*Lord*):

Carbonate of lime	53.98
Carbonate of magnesia	43.25
Silica	1.53
Alumina and oxide of iron	.40
Total	99.16

No test had been made of its lime-producing qualities until natural gas was discovered here, but the results of the analysis given above left

no question as to its excellent adaptation to this purpose. The first trials proved entirely satisfactory, and four kilns have now been put in operation, each of which will yield 75 to 100 barrels of lime per day. A. E. Royce has two kilns of the most modern type, with all the accessory equipment for a large production. W. Stanley Thurstin has also two thoroughly equipped kilns in successful operation.

Mr. Royce was the pioneer in this industry in northern Ohio. He visited Kittanning, Pennsylvania, the only point where lime-burning by natural gas is known to have been carried on before its establishment here, and examined carefully the conditions that had here been found necessary. His first kiln was not, however, entirely successful. It required, in fact, to be rebuilt, before it gave satisfactory results, but the problems connected with this mode of burning lime are being rapidly solved, and most of the lime now produced is of marketable quality. The trouble has been in overburning and in uneven quality resulting therefrom, for part of the time, and in underburning at other times, by which cores are left in the blocks. The gas is introduced through five burners on each side, under a pressure of two pounds. The flame can be sent through the entire kiln if desired. No doubt is left as to the complete success of natural gas in lime-burning.

The gas used in burning is piped to the kiln by the gas company, and is furnished at the rate of one cent per bushel of lime manufactured. The wood required for burning a bushel of lime will range in value between three and eight, or, possibly, ten cents. The average cost in the Springfield district, a dozen years ago, was between six and seven cents. The labor required in burning is reduced in probably an equal proportion. Under these new and remarkable conditions, competition on the part of the old methods is out of the question. Bowling Green lime has already made its way to the Cincinnati markets, among the most distant that it would naturally seek, where it finds it easy to establish itself after transportation by rail for at least 200 miles.

These facts naturally awaken a good deal of uneasiness in the large interest engaged in lime-production in northern Ohio. These subjects will be further discussed in a subsequent chapter.

The Growth of Bowling Green.

The effects of the discovery of gas in the town must be described in a few words. The population has been increased from 2,000 to 3,000 in the course of the last year. The price of real property has advanced from 100 to 300 per cent., and very many sales have been effected. A large amount of foreign capital has been brought in, the distribution of which has been quite general.

The central portions of the town have been bought up, the former owners, in many instances, erecting much better buildings elsewhere, from the proceeds of the sales. The outlying lands around the town have been bought up, platted and annexed. More than 100 new buildings have been put up within the last six months, and the work of construction is as active as ever at the present time. This growth is the result of the location of several manufactories in the town.

Bowling Green has been enterprising and fortunate enough to secure two glass works, viz., the Canastata Glass Works, of central New York, and the Lythgo Works, of eastern Ohio. The former of these has made the most costly and imposing plant that has yet been brought into the new field. It consists of two ten-pot furnaces for the manufacture of window-glass. A company of the citizens gave to the glass company, six acres of land for its buildings and $4,000 in cash, while the corporation promises free gas for five years.

The Lythgo Company is building at the present time. It has also received material aid from the citizens and town. It is to manufacture hollow glass-ware.

A foundry and machine shop have also been establised, and the machinery of the Pomeroy Rolling-mill is now in process of removal. Land and fuel are offered free to these and to all manufacturers.

The gas supply of the town is small, compared with that of Findlay. The corporation limits seem to be located on the extreme northern edge of the productive territory, and paying wells are first found a mile or more to the south of the court-house. Of this southern district, an account has already been given. While the volume of these wells is comparatively small, their pressure is high, and the supply seems ample for all the present and prospective needs of the town. The town has been wise and energetic as well as fortunate, and is reaping very great advantages from its newly found store of power.

No diminution of pressure has been thus far observed in the field.

The Portage Well.

The township of Portage, next south of that in which Bowling Green is located, has been already named in several connections. It constitutes, in fact, the gas territory on which Bowling Green is mainly dependent, and it therefore really comes under this last-named field, but one important well that was drilled here early in 1886 remains to be described. It is known as the Portage well. It was drilled by R. S. McMahan, for the sole purpose of obtaining fuel for lime production. The well has proved the best in the entire district. Its record is nearly identical with the records already given, but its flow of gas is natural, that is, the well

has not been shot. It has never yet been tubed and packed, and all its surplus gas, after supplying two lime-kilns, has been burned in the air. What is used in the kilns is a small fraction of the production of the well. At the least calculation 500,000,000 cubic feet of gas have been lost from this single well since it was brought in. The amount, indeed, is far larger than this. The daily production of the well slightly exceeds a million feet. The figures are as follows, viz., 1,010,880 cubic feet per day. The open pressure in a two-inch pipe at the well-head, is one and one-half pounds. In the calculation of the waste of the surplus, 210,880 feet were counted for the lime-kilns, and 800,000 for the surplus, but the amount named for the kilns is far in excess of their use.

Mr. McMahan has built two patent lime-kilns, with a capacity of 100 barrels each day. He burns the Niagara limestone, which he finds in characteristic excellence. He has availed himself of the experience of Bowling Green in this line of manufacture, and has perhaps improved upon it. At all events he has secured as good results as any one in the field.

To the south of the village of Portage, a sag in the strata occurs, as is evidenced by the appearance of the Waterlime as a surface rock. Two wells have recently been drilled in Sec. 16, Portage township, which show an abrupt descent of the series. The Dewitt well, in the N. E. $\frac{1}{4}$, found the Trenton at 1134 feet, or about 441 feet below tide. The rock lay a little too low for dry gas. A large volume of gas appeared, but a spray of oil comes with it and destroys the value of the well. Near the S. W. $\frac{1}{4}$ of same section, the Kinney well found the Trenton at 1268 feet, or 575 feet below tide. The fall of the oil-rock is seen to be 134 feet in less than one mile. The Kinney well was promptly overrun with salt-water. This sag cuts off all connection between the Findlay and Bowling Green gas fields.

THE LIMA OIL-FIELD.

Discovery of Oil at Lima.

Lima was the next town after Bowling Green, or the third in order in the new field, to try fortune by the drill. An important railroad center, already actively engaged in many lines of manufactures, full of energy and enterprise, and able to command sufficient capital for all promising ventures, it was easy to see that such a flow of natural gas as Findlay had secured would be of immense advantage here. The drill was first set to work by the Lima Straw Board Works, under the ener-

getic and sagacious direction of B. C. Faurot, Esq., and upon the grounds of the company.

Work was begun in the spring of 1885, by Brownyar and Martin, contractors. There was a double purpose in drilling at the Paper-mill, a better quality of water for manufacturing purposes being much desired, as well as a supply of natural gas.

The well was located within the grounds of the paper-mill and on the bank of the Ottawa River, the casing having an elevation of about 850 feet above tide-water. The drillers had by this time learned the general order of the strata to be expected, and consequently failed to keep the record of the drilling with as much care as in the fields first explored; but the section penetrated was seen to be, in the main, identical with the longer sections of the Findlay wells. The lower limestone was reached at a depth of about 1,250 feet, or about 400 feet below tide-water. A little gas had been found in descending through the shale, enough to light the mill in considerable part; but when the drill struck the Trenton limestone without releasing any additional amount, it was a serious disappointment to all concerned. This disappointment was somewhat relieved by the discovery of oil at the point where gas was looked for; but still the program had been arranged for gas, and the utilization of oil, even if found in large enough quantities to be valuable, was a much less simple matter. But the well having proved a failure as a source of gas, the only thing to be done with it was to treat it as an oil-well. It was, accordingly, "shot" with a charge of rack-rock, with apparently good results, and was forthwith tubed, packed and pumped. During the first six days it yielded more than 200 barrels of oil, carrying some salt-water. Mr. W. M. Martin, the contractor in charge, estimated it at the time as an eighteen-barrel well, this being the most favorable view that could be taken of it. The oil was like that found in the first Findlay well, dark in color, low in gravity, and offensive in odor. To those acquainted only with oils of the Pennsylvania type, these characteristics seemed to condemn the new supply.

But the news that Lima had "struck oil" at once attracted the attention of the wakeful men who have control of the great petroleum interests of the country. The possibility of a new oil-field came at an opportune time. For nearly a year, in spite of multiplying wells, petroleum production had fallen below consumption, and stocks at the great centers were being steadily reduced. To most of the visitors to the new district, and to most of the oil operators who inquired as to its capabilities, however, there seemed but little promise. All of the conditions were unusual; the surface of the country was flat; its elevation above the sea was comparatively small; and, worst of all, the producing

rock was a limestone. In addition to this, and in consequence of the last-named fact, sulphur compounds abounded in the water, gas and oil of the wells to an unusual degree. These facts were enough to discourage many who would have eagerly followed up equal indications of oil, if conformed to previous experience. The representative of an important Pennsylvania company, however, I. E. Dean, Esq., who was among the first to visit Lima in this interest, had been engaged at one time in the Canada oil-field, and was thoroughly conversant with its history and value. Mr. Dean was the first to recognize the possibilities here, and with his intelligent and energetic administration, much of the present development has been connected. The Trenton Rock Oil Company, organized by him, has had a prominent place in the development of the new territory. Much of the earlier work undertaken by this company has had its only value in defining the field. Its first five wells all proved complete failures. These wells were located on the northeast lines derived from Pennsylvania experience, and so also was the bulk of the extremely large acreage of drilling privileges belonging to the Trenton Company. In fact the company secured a broad and almost continuous belt, extending from Lima to Findlay, and within which it was supposed the principal possibilities of the field would necessarily be included, but history did not repeat itself in this respect. These northeast lines and belts were soon found, by the discerning, to be entirely without significance, so far as oil accumulation was concerned. Nearly all of the best production lies outside of the belt which was first occupied, and those who came last were driven to locate, to their own great profit, in what has proved the most prolific portion of the entire field.

The discovery of oil at Lima was made in the way described, but the second well, known also as the Citizens' well, had also a very important office in the authentication of the new field. Soon after the presence of oil in the Trenton limestone had been demonstrated, a number of public-spirited gentlemen effected an organization under the name of the Citizens' Gas Company, the specific object of which was to obtain for themselves, with reference to the interest and advantage of the town, the actual facts as to the existence and production of oil here. It was an honorable office that was assigned to this well, and it effectively served the purpose for which it was drilled. In intrinsic importance in the development of the field, it stands scarcely second to the pioneer well. It is to be credited, in fact, with yielding the first regular and persistent supply of petroleum from the Trenton limestone in Ohio, the pioneer well meeting with a series of misfortunes that left it useless. It was completed in the fall of 1885, and it began its course as a forty or forty-five barrel pumping well. It showed, from the first, steadiness and

reliability. In December, 1885, it yielded 1,450 barrels of oil, and in the first three months of 1886, it produced an average of twenty-six barrels per day. It was the oil of this well that was first sent to the refineries of the country to be tested on a large scale, and the results obtained from such examinations were believed to establish the fact that Lima oil could be thoroughly deodorized and made to yield a good percentage of illuminating oil of the finest character.

The two wells now described determined by their behavior the fact that Lima was henceforth to be counted an oil-field. Since their completion, and the consequent authentication of the new territory, the development has been very rapid and successful, and the field has risen in importance until, at the present time, it is unquestionably not on y the most important oil-field that Ohio has ever had, but by all odds the most important field, so far as the posibilities of production are concerned, yet found on the American continent. If second to any field in the world, it is only to the wonderful fountains of Baku, on the shores of the Caspian. On April 1, 1885, the pioneer well was drilled. Nearly a year was required to convince the drilling community that there was a field here worthy of development. In April, 1886, 14 wells had been drilled; on May 1, there were 22 wells; on June 1, 34; on July 1, 57; on September 1, 128; on October 1, 139 producing wells; on November 1, 165 producing wells. Of the October number, 165, nineteen are flowing wells, seventeen have been abandoned, and the rest are pumping wells of varying capacities. Counting the united yield of each well to continue through the month, the daily yield in September was about 4,500 barrels; in October, about 7,000 barrels, in November, about 8,300; in December 9,500 barrels; in January, 1887, 8,500 barrels; in February 11,700 barrels; in April 10,400 barrels. The number of wells drilled at this time was 424. Of the 20 wells drilled in April, but one was dry. The average production of these 20 wells was $81\frac{1}{2}$ barrels. The arrested development of the field will be explained on a later page.

The topography and the geology of the district will next be briefly discussed, after which a succinct history of the field will be given.

Topography of the Lima Field.

The surface of Lima and its immediate vicinity is not as monotonous as that of many other portions of northwestern Ohio. It has more relief than either of the districts already described, and yet its range will not exceed fifty or seventy-five feet.

The elevation of the intersection of the three roads that cross the northern part of the town is variously given. Each road, in fact, reports

an elevation of its own. In Gannett's list (United States Geological Survey) they are given as follows, viz.:

Dayton and Michigan Railroad	859 feet.
Lake Erie and Western Railroad	885 "
Pittsburgh, Ft. Wayne and Chicago Railroad	779 "

The last figure is clearly an error, and probably an error of an even 100 feet. The D. and M. figure probably needs correction by an addition of eight feet for the newly determined level of Lake Erie (573 feet above tide-water instead of 565 feet above). Mr. Thomas Jackson, Division Engineer of the P., Ft. W. & C. Railway, from the records of his office, gives the elevation of the point in question as 873.5 feet. The Chicago and Atlantic Railway on the south side of the town reports 903 feet as the elevation of the iron on the track at its Lima Station. Inasmuch as the figures of the Lake Erie and Western Railway have been used in the Findlay field, they being the only ones accessible there, they will also be adopted here, although it is probable that they are about twelve feet above the real level.

The range between 850 and 900 feet will, probably, reach almost every point in the uplands in and around Lima.

The valley of the Ottawa River, which flows through the town, makes the chief feature in its relief. With the main valley, the valleys of the tributary streams must also be reckoned. The elevation of the comparatively narrow bottom lands in these valleys is not far from 850 feet.

The facts now given will enable the reader to understand the chief features in the topography of Lima. In the map which accompanies this report, the locations of all the oil-wells drilled to date, within the limits of Lima and in the immediately adjacent territory, are indicated, and the elevation above sea-level of a number of the wells is given, such figures being enclosed in squares.

Geology of the Lima Field.

a. Geological Section.

The geological section found at Lima is identical with the longer sections at Findlay. Drift-beds cover the entire surface to a depth varying from eight feet to one hundred feet. The surface rock is the Waterlime, or Lower Helderberg limestone. It appears in the bed of the river and in many of the tributary streams of the neighborhood. In physical characters, the stone agrees with the formation generally throughout northern Ohio, but some of these characters are more fully developed here than at other points. The rock is extremely compact and strong

at several exposures. It is also darker blue in color than is common. Furthermore, it is, in some localities, unusually fossiliferous for this formation. The fossils contained in it are different, to some extent, from those that are counted characteristic. Among the forms identified here, *Meristina sulcata* is the most abundant, while the common *Leperditia* is rare or wanting. Sections of the limestone, twenty to thirty feet in thickness, are shown in the town quarries, but this depth is maintained only by the constant use of the pump, the floor being below the level of the water in the river bed.

Underneath the Waterlime, the Niagara limestone, the Niagara shale and the Clinton limestone and shale are found in all of the wells, constituting, with the first-named stratum, the so-called "upper limestone" of the drillers. The whole series is commonly called by them the Niagara limestone. The entire series is here 350 to 400 feet thick. The separate divisions of it are not recognizable, as a rule, in the well records, but it is certain that the several elements appear in all of the drillings, when proper care is given to the keeping of the record.

The Niagara shale is a water horizon, and the Clinton group probably includes both limestones and shales. It seems, also, to have a greater thickness here than it has in its southern outcrops.

The Medina shale appears here as a blue and hard slate. The characteristic red color has not been reported in any Lima well as yet, but it is quite likely to be found in the wells to be drilled, inasmuch as it almost uniformly appears to the north, the east, and the south of Lima, and sometimes to the westward. The thickness of the Medina cannot be given with precision.

The Hudson River shales are blue and gray, and contain many, but thin, layers of limestone. The entire series is about 500 to 550 feet thick.

The Utica shale is dark-brown, verging at its base into black. It is about 300 feet in thickness. The entire shale formation is 840 to 850 feet thick, but, as already intimated, the subdivisions of it are not, in all cases, separated from each other by sharp and recognizable boundary lines.

The Trenton limestone that comes next below is the oil-rock. It is not generally penetrated more than fifteen to twenty-five feet in the Lima wells. The following divisions of it seem fairly constant, viz.:

Hard-cap, crystalline limestone	3 to 7 feet.
Oil-rock, very porous generally	7 to 15 "
Salt-rock, hard and fine-grained, and yielding strong brine.	

In the cap some gas is generally found, and sometimes a little oil. The oil-rock is often divisible into more than one oil-producing horizon.

When two or more horizons are found, they are generally separated from each other by four to six feet. The porosity of the oil-rock, which is marked, is due to the imperfect interlocking of the dolomitic crystals of which it consists. It is entirely crystalline in structure, and no fossils have been detected in this part of the stratum when it holds the dolomitic character referred to above. The salt-rock is merely a firm, hard phase of the limestone.

This whole Trenton series, as found here, is known by the drillers as sand. They distinguish the divisions already named as the upper, or gas-sand, the oil-sand, the salt-sand, etc. They sometimes go so far as to identify a first, second, and third oil sand. All this is imported from Pennsylvania experience. Oil and gas, in the great eastern fields, are almost entirely confined to sand-rocks, and in the original or Venango field, there were three of these sandstone strata included within 350 to 500 feet that were the repositories of the great stores accumulated there. The three oil-sands of Venango were made, as new fields were discovered, to do universal service, even in entirely distinct and widely-separated horizons. It has just been shown that they are brought down a dozen steps in the scale and made to apply, also, to mineralogical changes of limestones of ordinary type.

The Lima oil-rock, like the Trenton throughout the northwest generally, is a magnesian limestone, containing from twenty-four to thirty-nine per cent. of carbonate of magnesia. The composition is shown in the following analyses. For comparison, the composition of the same stratum at a few other points in the vicinity is here given, and a single

1. Lima well, No. 1.
2. Woolsey well, Lima.
3. Hume well, Lima.
4. Findlay well, No. 1.
5. Bowling Green well, No. 1.
6. Bryan Well, No. 3.

	1	2	3	4	5	6
Carbonate of lime	52.66	55.90	63.46	53.30	51.78	49.00
Carbonate of magnesia	37.53	38.85	24.20	43.03	36.80	38.59
Insoluble residue	4.15	.75	5.10	1.70	4.89	9.22
Oxide of iron and alumina		2.94	2.75	1.25		1.51
Organic matter and loss		1.56	4.49			
		100.00	100.00			98.32

The oil rock is seen to be, as already claimed, a limestone of fair composition. All of it could be burned into good lime, and some of it, as that from the Woolsey well, would make lime of the highest quality. All the "sand" that belongs to it must be included in the one to ten per cent. of "insoluble residue," and this is by no means all sand or silica. There is, in fact, as little true "sand" in the limestone of the oil-field as in any other rock formation of the state. It is greatly to be regretted that such a misnomer should be fastened upon the Trenton limestone, one of the most widely distributed and most definitely characterized formations of the entire geological scale of the country.

There was no minute account kept of the strata traversed in the pioneer well at Lima, as has been already stated, but among the early wells of the town, the progress of one put down by the Gas Company, near the city gas-works, was followed with care and intelligence. This record has been kindly furnished to the survey by Mr. A. C. Reichelderfer, Secretary of the company. It is as follows:

Drift	18 feet.
Limestone beginning at	18 "
Sulphur water, large vein, at	128 "
White limestone, "marble" at	268 "
Blue limestone at	328 "
Limestone with slate streaks to	385 "
Shale, with no more water, begins at	395 "
Brown shale at	880 "
Black shale, thin, begins at	1,228 "
Oil-rock, hard shell, struck at	1,243 "
Oil-producing, best	1,255 "
Salt-rock, softer, (?) slushy	1,260 "

In the light of the facts already stated, the interpretation of the series here displayed is obvious. It can be generalized as follows:

Drift		18 feet.
Upper Silurian Limestones	Waterlime. Niagara limestone. Niagara shale. Clinton limestone. Clinton shale.	400 feet.
Medina and Hudson River shales		450 feet.
Utica shale		350 feet.

The subdivisions of the several elements it is not always possible to clearly make. For example, we are not able to say just what number of feet in the Upper Silurian limestones belongs to the Waterlime or the Niagara or Clinton limestones. The last-named stratum is probably thicker in northern Ohio than to the southward. It embraces blue and white limestones, alternating with thin beds of shale. Occasionally a

band of red limestone is found at this horizon. An approximate general section for the Lima district would probably be about as follows:

Waterlime	100 to 500 feet.
Niagara limestone and shale	250 "
Clinton limestone and shale	100 "
Medina shale	50 "
Hudson River shale	550 "
Utica shale	250 to 300 "
Trenton limestone.	

The geological section of the Lima field has now been given. From the statements made, it is seen that under beds of drift varying widely in amount, a compound series of limestones is met which ranges from 300 to 400 feet in thickness. Beneath the limestones, 850 feet of shales, gray or greenish-blue in the upper half and dark in the lower, are found. Under the shales, and separated from them by a boundary generally as distinct as a chalk-line on a blackboard, lies the Trenton limestone. Its depth below the surface is 1,200 to 1,250 feet.

b. Geological Structure.

The geological structure of this field remains to be briefly described. Under this head, the dip or inclination of the strata is the principal topic to be considered. If faults or fractures were to be found, they, too, would come under this head. The main interest centers in the facts pertaining to the Trenton limestone, whether lying relatively high or low at any point, as gas, oil, and salt-water adjust themselves in this respect with great nicety to its varying levels with reference to the adjacent territory. It has been already stated that the drift deposits, by which the surface of the country is covered, are unequal in thickness in different localities. These inequalities correspond to the inequalities in the surface of the Waterlime, or upper limestone, and not to its dip, as is often supposed. Before the drift beds were brought in, the limestone floor of the country was very extensively eroded, deep channels being cut in it for the former drainage systems of the land. These ancient furrows were smoothed over by the drift, as the furrows of a plowed field are obliterated by a driving snow-storm. The only determination of dip that is possible must be based on the level of the lower surface of the upper limestones, or on the level of the upper surface of the Trenton limestone, these being the only horizons at Lima that are definitely and certainly recognizable. As established by the numerous wells in the Lima district, the Trenton limestone here lies as nearly level as any sheet of rock is ever found. There is a slight general declination to the northward, but there are many square miles in

which this feature scarcely shows itself. In one square mile, for example, on which fifty or more wells have been drilled, the extreme range of difference in the depth at which the Trenton was found, is sixteen feet, and excluding a single well, the range is only nine feet. Two wells, one mile distant from each other, in a north and south line, differ but three feet in the depth at which the Trenton was struck, and two wells a mile distant in an east and west line, found the limestone at exactly the same level. Taking a longer range in an approximately north and south line, viz., from the Christ. Martin well, section 20, Perry township, to the Hoffman well, section 17, Bath township, a distance of six and a half miles, the fall is found to be fifty-seven feet, an average of nine and a half feet to the mile. This exceeds the normal descent of the Trenton limestone in Ohio, and it is important to note how the descent is distributed. From the Martin to the McDonald well, No. 1, a distance of one mile, there is a fall of two feet, while to the adjacent McClain well there is a rise of one foot. For this mile, therefore, the rock lies level. From the Martin well to the Hogle well, a distance of one and a half miles, there is a fall of six feet, and to the Ditzler well, two miles, a fall of nine feet. From the Martin well to the Faze well, a distance of three and a half miles, the fall is twenty-six feet, but to the next well on the same line, viz., the McCullough wells, Nos. 1 and 2, the fall is but twelve feet. This makes nearly the northern limit of good oil ground, as at present known. From the Martin well to the Collins well, a distance of four and a half miles, the descent is twenty-four feet, but the Collins well lies outside the present limit of productive territory, certainly by half a mile. From the McCullough, No. 2, to the Hoffman well, the fall is forty-five feet, which shows the rate to be fifteen feet to the mile for this part of the region here included. Taking an east and west line through the southern part of the corporation of Lima, we obtain an instructive section. Beginning with the Ashton well on the west, in which the Trenton was found 402 feet below tide, and moving to the eastward, we find the Dingledine at 392 feet, the Simons well, No. 1, at 388 feet, the Garvey well, at 381 feet, the McCullough wells, Nos. 1 and 2, at 388 and 389 feet, the Shade, No. 1, at 390 feet, the Faze (abnormal) at 402 feet, the Tunget at 386 feet, the French at 387 feet, and the Parker at 408 feet. South of the Parker are the Heffner and the Tapscott, at 405 and 404 feet, respectively. The length of the line traversed is four miles. There is a difference in the extreme stations of six feet in the level of the Trenton, but the Faze well, in the middle of the line, is at the exact level of the initial well. But the fact of special interest is that neither of the extremes is productive, nor is the Faze well, while a line of excellent wells occupies

the middle ground and higher elevations. The Simons, No. 1, the Shade, the McCullough, the Tunget, and the French, the extremes of which are three miles apart, show the level of the oil-rock to be 388, 390, 389, 388, 386, and 387 feet, respectively. In the Garvey gas-well, within the same limit, the limestone rises to 381 feet. There is an intervening dip, or salt-water swamp, of slight extent, as shown in the Faze well.

We find, therefore, that the Trenton limestone, in the productive portion of the Lima field, occurs as a flat-lying terrace, with fairly well-marked boundaries of steeper descent on the east, west and north. The southern boundary is not yet clearly determined, but the Trenton has not been found productive, thus far, where it is less than 370 feet below sea-level. No fractures, like the main line of disturbance at Findlay, have been brought to light in this district, but slight rolls, or domes, or hollows, occur within the terrace, all deviations from the general level not exceeding, for the most part, five to ten feet.

It would be premature, at this time, to discuss the effect of this structure on oil and gas accumulation in Lima; but upon a later page, after the leading facts of production have been presented, the subject will be again taken up, and some important deductions from the experience thus far gained will then be given. Some of the interesting conclusions in this connection are, in fact, already coming incidentally to light in the statements above given.

Development of the Lima Oil Field.

The discovery of oil at Lima has now been described, and the essential features in the topography and geology of the new field have been briefly set forth. A succinct account of its progress and of its present development is next in order. In connection with this, the character of the oil will here be treated, and aso the means provided for its transportation, storage and refining.

Lima oil was discovered in May, 1885. Territory soon began to be leased on a large scale with reference to drilling, but it was not until about the middle of July that the projects for new work took definite shape. Contracts were let for the Citizens' well on July 9th. The coming in and behavior of this well have been already alluded to under the first section. It is located in the Ottawa Valley, near the center of the town. The casing stands at an elevation of 842 feet above tide. About twenty-six days were occupied in sinking it. The upper limestones ended at a depth of 371 feet, and the Trenton was found at a depth of 1,236 feet, or 395 feet below the sea. Salt-water was reached in the Trenton, and was brought out with the first oil in the proportion of one of salt-water to two of oil, and it has always followed closely upon

the oil. Any interruption of pumping allows the brine to overpower the oil, and the work is, accordingly, kept up continuously night and day. The city council, at one time, required pumping, like other branches of business, to be suspended on Sunday. The consequence of a single compliance with the law was, that the well ran down from eleven inches of oil in the tank to eight and a half on Monday, and was an entire week in recovering its flow. The well has been an expensive one. It has probably cost more than $5,000, pumping included, and it is doubtful whether it has earned, all told, half that amount. It was worked for a time with a daily product of fifteen barrels, but the shrinking price of Lima oil made it impossible to continue, and the well is now abandoned. Wells have been crowded in upon it almost as close as the subdivision of city lots would allow, and few of these wells, if any, will be able to return the money so unwisely invested in them. An oil-well, as oil-wells generally go, must pay for itself within a year, if ever.

The Trenton Rock Oil Company was busy during these months in proving territory. It laid out a line of wells between Lima and Findlay, and was interested in various other tests that were going forward in the surrounding country. All the wells in the Findlay line proved unproductive, including the Firmin well, which was about two miles west of the Findlay corporation line. Among these early failures was the Hoffman well, which found the Trenton 433 feet below tide, and full of salt-water; the Smith well, in which the Trenton was 407 feet below tide and unproductive; the Snyder well, at Beaver Dam, in which the Trenton was 422 feet below tide, and unproductive.

There was nothing especially encouraging in the facts that appeared in January, 1886, but on February 2d, the Moore and Brotherton well displayed, as it was brought in, a vigor not shown in those that preceded it. It was reported to have thrown oil 170 feet above the casing, when the tools were first removed, and was, indeed, the first to show gas enough to raise the oil. On the third day, it was rated at 70 barrels. During the month of February it produced 1,000 barrels, and in March 700 barrels, the energy of the gas gradually dying down. In April, a pump was put in to increase the flow, but no advantage was apparent from the change. The well gained a temporary increase from the effect of a torpedo, but at the present time it is not yielding any oil. For some time it produced gas enough to keep the pumps in operation, and was thus worked with much more economy than those previously described. The oil-rock, in this well, was found 397 feet below tide-water.

The Wise well, located in the same immediate neighborhood with

the two last described, came in about this time. It has always been a light producer.

A well of larger yield and greater vigor was brought in early in March on the Shade farm, a mile to the southeast of the town. This well deserves to be counted among the most important of the early wells, because of the great extension that it gave to the limits of the field. The Trenton limestone was found in it 390 feet below tide-water, and the flow of gas was much more energetic than had been found in any previous well. This well proved, in fact, a true flowing well. At first, it was reported at 350 barrels, but this was a greatly exaggerated estimate. It retained gas enough to raise the oil for several months. It is now a pumping well, and is reduced in daily yield to twenty barrels, or thereabouts. The tract in which it stands became a favorite drilling ground, and a number of wells have since been drilled upon it, with more to follow. Adjacent territory was also eagerly occupied, and several wells of this general type were presently found in this immediate neighborhood.

The Ashton well was located to the west and south of the town, and was drilled a little earlier than those last described. Neither oil nor gas was yielded by the Trenton limestone here, but there was a large amount of salt-water. The limestone was struck at 402 feet below tide. The failure of this well served to discourage drilling in this direction, for a long while, and, in fact, but few attempts have been made beyond it, to the present date.

On April 20, twenty wells had been put down in the Lima field, or by Lima interests, in the outlying country between Findlay and Lima. The last of this number, the Hume, was brought in on that day, and during the first twenty-four hours, it put 250 barrels of oil in the tank. It was, by a few feet, the shallowest of the group of wells among which it was situated, and, as has been shown, it was also the most vigorous of the group. Its production was decidedly the largest up to this date, and all doubt was now dispelled as to the presence of oil in large enough amount and accompanied with gas of high enough tension to make Lima an oil-field deserving of the name. The confidence of the drillers, who had been spending money so freely for a year was at length justified, and the most conservative observer found no longer need for suspense of judgment. This well is located near the center of the town. The casing is 840 feet above tide. The depth of the well to the Trenton is 1,233 feet, and consequently, the level of the Trenton below tide is 393 feet.

By this time it had become apparent that oil could probably be had

in greater or less quantities under every city lot in Lima, and the consequence naturally to be expected followed forthwith. Wells were crowded together, two or three to the acre, in some cases. It will only be in exceptional cases that any of these wells will return the money spent upon them; and, though the policy of drilling in this fashion was short-sighted and wasteful to a high degree, it was one of the inevitable consequences of the facts involved. This experience has now passed, however. The drillers lingered around the valley of the Ottawa and the adjacent lots, because, up to this time, the best fortune had attended the wells that were located here. But a number of test wells in the outlying territory, some of which have been a ready reported, and especially to the east of south of the town, were finished in the early summer. Many of them showed a great advance on all that had preceded them. Wells were brought in on the Bowman, McClain and Ditzler farms, yielding respectively 125, 140 and 500 barrels for the first day. At about the same time, a fine body of oil-land was found three miles east of the town. The French well, with 300 barrels, and the Tunget well, brought in August 6, 1886, with 700 barrels for the first day's flow, divided the honors fairly with the southern area already noticed. The Tunget was, for a while, in the lead of the entire field. In the first three months, it flowed over 14,000 barrels, and at the end of that time was still flowing at the rate of 100 barrels per day. It is producing Sept. 1st, 1887, 25 to 30 barrels per day.

Another fine territory has since been developed to the south and west of the first-named belt of large wells. The Spear, the Lehman, the Ballard, the Hueston wells are all of the best character. In October, 1886, a well was finished on the Douglas farm, directly north of the Tunget, that nearly equaled the latter well, and that thus takes its place among the leading producers of the new field.

The Douglass well has yielded up to August 1st, 1887, 22,788 barrels of oil, and is now producing an average of at least 60 barrels per day.

The predictions of experienced operators, that wells yielding one thousand barrels per day would be struck in the Lima district, seemed, when such predictions were made in the days of twenty, thirty and forty-barrel wells, in the highest degree improbable and extravagant; but those who watched the development of the summer and fall of 1887, became less and less disposed to question the possibility of their truth. The verification of these predictions was reached late in October, when the well of Collins, Leonard & Co., on the Alonzo McClain farm, Sec. 13, Shawnee township, was drilled into the Trenton limestone. It is located among the valuable wells already named, about three and one-half miles south of Lima. After being "shot" its first hour's flow was

sixty-five barrels, and its first day's yield was nearly 1,000 barrels. The life of this great well is also remarkable. In its first 9 months flow it had produced 60,000 barrels of oil and was flowing at the end of this term at the rate of 150 barrels per day.

Soon afterwards the W. G. Fee well on the J. W. Ridenour farm, Sec. 18, Perry township, was brought in, and its first day's record left everything that had been thus far found in the new field, far behind. It started out with a production of 115 barrels per hour, and at the end of 24 hours had put 2,760 barrels into the tank.

Another well deserves special mention in this connection, because of the great extension that it promised to the Lima field. It is known as the Sellers well, and is located about one and one-half miles east of Cridersville. The accounts first published agreed in representing it as a large well, yielding 100 or more barrels per day. It is seven miles south of Lima, and lies beyond the Allen county line. Another well, drilled a little to the east at Uniopolis, came in at about the same time, and is unproductive, while a well going down at the west of Cridersville suffered great disadvantage from finding the drift beds more than 200 feet thick. The Phillips well in Sec. 26, Shawnee township, proved a valuable one, and it served to establish the claim of a considerable area of new territory.

In the region around Cridersville another one of the prolific pools of the Lima field was presently brought to light. Wells of large production and great steadiness are found there. The Delong and Kemper farms and numerous other tracts in sections 33, 34 and 35, Duchouquet township, Auglaize county, have been already more or less developed, and prove to be first-class territory in every respect. In steadiness this part of the field is not surpassed. A well, for example, that started in May with 150 barrels is found in August to be still flowing eighty barrels per day.

The Lima oil-field has now been briefly reviewed. It is seen on the accompanying map to include in whole or in part the following territory, viz:

Allen county, Ottowa township, Section 36.

Allen county, Bath township, Section 33, 34.

Allen county, Perry township, Section 5, 6, 7, 8, 9, 16, 17, 18, 19, 20, 29, 30.

Allen county, Shawnee township, Section 13, 23, 4, 5, 6, 7.

Auglaize county, Duchouquet township, Section 2, 3, 4, 5, 31, 32, 33, 34, 35, 36.

Within these twenty-five or thirty square miles there are many barren tracts, but valuable wells are in order throughout the whole. The

best territory lies in patches or pools, and these separate pools do not show any system of arrangement thus far. They are not in northeast lines.

The wells that have any suitable advantage in the matter of elevation of the oil-rock prove to be flowing wells. This spontaneous production in some cases is maintained for a year, but it generally ceases in half this time. When the pump is introduced a new lease of life is generally obtained for the wells. Other wells, and in fact the majority require to be pumped from the beginning.

Salt-water is often found in the oil-rock, but its presence does not prove destructive or even unfriendly to production in all cases. As a rule it gains upon the oil in the wells in which it originally appears, and finally overcomes it. In other wells it makes its appearance later, but it will doubtless be found in all as the field acquires greater age. It is often brought in by the use of torpedoes in disastrous floods. Most wells are improved by being shot, but others, as stated above, are robbed of whatever promise they first had by this operation.

As to the boundaries of the field, little needs to be added. On the north they are distinct, and there is no promise apparent in that direction. This boundary depends on the depth at which the Trenton limestone is found. There is also a well defined boundary on the east and south, with but little promise that it will be passed in any important exceptions. The reasons for this belief are mainly founded on the change in the composition of the oil-rock that appears as it is followed in these directions. It loses the dolomitic character that is inseparably connected with large production so far as present experience goes.

To the westward, the boundaries do not yet appear. There is room for important additions to the productive territory on this side of the field. The northeastern tests have thus far all been disappointing.

As to its capabilities of production, it need only be said that, all who are competent to judge, rank the field extraordinarily high. Its development has been systematically and vigorously repressed, thus far, but in spite of all discouragements, the August production (1887) of Trenton limestone oil in Ohio exceeds 15,000 barrels per day. The present price is fifteen cents. Doubling the price would undoubtedly double the production in less than 90 days. Trebling the price would in the opinion of judicious men increase the production to four times its present volume in less than 180 days. These estimates are sober and conservative. Intelligent operators can be found who would double both of the estimates already made.

The relation between the levels at which the Trenton limestone is reached in the wells, and their production of oil and gas has been adverted to already in several connections. The following list of wells

Name of well.	Trenton limestone below sea-level.	First day's production.
Amos McClain	375 feet (well shot)	140 barrels.
Christ. Martin	376 "	20 "
McDonald, No. 1	378 "	70 "
Garvey's Gas Well	381 "	
Bowman	382 "	125 barrels.
Hogle	382 "	50 "
Ditzler	383 "	500 "
D. Martin	384 "	15 "
Tunget	386 "	700 barrels.
French	387 "	300 "
Lehman	387 "	70 "
Apple	387 "	70 "
McCullough, No. 2	388 "	20 "
Steelsmith	388 "	
Simons, No. 1	388 "	10 barrels.
Locke	389 "	10 "
Sarah Jacobs	389 "	10 "
McCullough, No. 1	389 "	20 "
Shade, No. 1	390 "	20 "
Wheeler Well	391 "	
Reese, No. 2	391 "	40 barrels.
Reese, No. 3	391 "	40 "
Holmes, No. 1	391 "	30 "
Harrod	392 "	8 "
Dingledine	392 "	10 "
Reese, No. 4	392 "	30 "
Hume	392 "	250 "
Gas Company's Well	394 "	
Paper-mill, No. 2	395 "	20 "
Citizens'	395 "	35 "
Reichelderfer	396 "	10 "
Holmes, No. 2	396 "	30 "
Chicago, No. 1	396 "	8 "
Fritz	397 "	10 "
Moore and Brotherton	397 "	12 "
Simons, No. 2	399 "	Abandoned.
Collins	400 "	"
Ashton	402 "	"
Faze	402 "	"
Ehrich	403 "	"
Hefner	404 "	"
Boose	404 "	"
Tapscott	405 "	"
Woolsey	406 "	"
Smith	407 "	"
Roberts	408 "	"
Parker	408 "	"
Woolet	410 "	"
Cole	416 "	"
May	421 "	"
Hadsell	432 "	"
Hoffman	433 "	"

in which the levels of the limestone have been determined illustrates this subject in a striking way. If all the new facts were gathered in there is good reason to believe that they would simply confirm and extend the conclusions that here come out to view. All intelligent ope-

rators now recognize the paramount importance of this feature. Their judgements as to the promise and behavior of a well are largely shaped by the depth at which the oil rock is found. The list embraces over fifty wells that are arranged in the order of the elevation of the Trenton limestone as found in them. There has been no selection of facts whatever. Every record that was readily accessible at the time the measurements were made was put into the list, and it is entirely probable that all the subsequent records would fall within the limits that are here shown. The first day's flow of every well is also given in all the cases in which it could be definitely ascertained. The wells were nearly all measured by the steel tape, and the figures are as accurate as such measurements generally are. Few, if any, anomalies exist; but even these few would perhaps disappear upon a more careful examination of the records. (The elevations of the surface were determined for the Survey by Mr. J. C. McCullough, of Lima.)

The very important questions as to the character, proper uses and value of the oil of the new horizon will be reserved for discussion in a later section, after the facts of production have all been given.

The Trenton Limestone at other Points in Northwestern Ohio.

The first three centers of oil and gas production for the new horizon have now been briefly reviewed. Each of these fields has been gradually extended beyond the limits of the town in which the development began; and it is true that as these fields are understood at the present time they embrace almost the entire production of the Trenton limestone in the state. There are, however, several distinct centers of gas production only partially developed as yet, viz., Bloomdale and Bairdstown, intermediate between Findlay and Bowling Green. These wells show large promise, and do not naturally belong to either the Findlay or the Bowling Green district.

Findlay, Bowling Green and Lima were, as has been shown, the first three towns in northwestern Ohio to drill to the Trenton limestone. All were successful in finding gas, or oil, or both. It was altogether natural that all the towns around them should be incited by this uniform success to start the drill for themselves. In fact the success of Findlay alone had exerted the same influence on every enterprising town in its section of the state that Bowling Green and Lima had already responded to in drilling their wells; and now that these towns, which happened to be the first to make the trial, had also found the new horizon charged with gas or oil, it seemed scarcely less than a demonstration that every neighborhood that had the energy to drill

1,000 or 1,500 feet into the underlying rocks would be rewarded as these first-named towns had been. The geological conditions that were observed at Findlay and Lima were certainly widely extended through the district. Almost the entire surface of this quarter of the state is underlain by Upper Silurian limestones, or at least by these limestones reinforced, as they are in two small areas, by the Devonian limestone and shales. There are fifty counties of the western half of Ohio, and in at least forty-eight of them the Trenton limestone has been reached by the drill within two years, and many of these counties have put down more than a single well. Not only have several wells been drilled in a single town in many cases, but drilling has also been done at two, three, or even a dozen points within the county, not to speak of those counties in which the wells are counted by the score, or even by the hundred. It would require a volume to follow out the entire development of this portion of the state on the scale that has been already employed in the territory now described; but a cursory review of the remainder of the district will be here undertaken, in which special attention will be given to the rich harvest of geological facts that has been yielded by these explorations. It will not be necessary to pursue, in this review, a strict chronological order, nor will an exhaustive record of all the drillings undertaken in the new field be required. The convenience of the reader will be served by the adoption of a geographical order, in the main, in the accounts now to follow. The wells already described are located in the counties of Hancock, Wood and Allen. Those to be described in the next ensuing sections are to be found mainly in Ottawa, Sandusky, Erie, Huron, Seneca, Wyandot and Marion counties.

The Fremont Gas-Wells.

On the Lake Erie and Western Railway, to the northeast of Findlay, there are three prominent towns, viz., Fostoria, Fremont and Sandusky. Each of these towns has drilled one or more wells to the Trenton limestone within the last two years, and one of them has attained a measure of success in the discovery of a supply of gas adequate to household, but not to manufacturing use, and to the former only on a small and definitely restricted scale. Fremont began to drill in May, 1885. The location of the town was thought, at the time, to be advantageous, so far as the new horizon was concerned. It was generally assumed that the gas of Findlay was derived from the old but little known fold that traverses the strata of Ohio under the name of the Cincinnati axis, although this fold had heretofore been located further to the eastward. The geological facts at this time in hand seemed to indicate the extension

of the axis in the general direction of Fremont, and some encouragement was accordingly taken from this fact. The drilling was undertaken by the gas company of the town. The well was located in the lower level of the valley, and about 600 feet above tide-water. The contractor was J. E. Brownyar. The work went forward rapidly, and the Trenton was reached on July 8, at a depth of 1,328 feet. The Trenton limestone is thus seen to lie at the depth of about 720 feet below tide. The record of the well, as kept by the drillers, is as follows:

Upper limestones, variously colored	360 feet.
Clay streak in which the well was cased	——
Shales—blue, red, brown and black	968 "
Trenton limestone, at	1,328 "

A very complete set of samples of the drillings was kept by Mr. R. B. Hayes, Jr., duplicates of which were kindly furnished to the Geological Survey, and which have proved of great interest and value in the interpretation of the record. Analyzed in the light of these samples, the section found in the well is about as follows:

1.	Niagara limestone, solid	200 feet.
2.	Niagara limestone, slaty, and ending in white clay	60 "
3.	Clinton limestones and blue calcareous shales	100 "
4.	Medina shale, red	110 "
5.	Hudson River shales, gray, green and blue	450 "
6.	Utica shales, dark, and finally black	308 "
7.	Trenton limestone, at	1,328 "

Fossiliferous chips occurred in the drillings at various horizons, and some of the forms were identifiable. On torpedoing the well, large fragments were obtained which threw more light upon some of the several divisions. The boundaries between the formations noted are not, in all cases, distinct. Especially is it hard to draw the line between the third and fourth, and also between the fifth and sixth. There is a general shading in color and in chemical composition in both cases, which makes any line that would be drawn somewhat arbitrary. Between 400 and 600 feet, quite large supplies of gas were found at several horizons, but notably at about 450 feet. This will be recognized as the line of junction of the Niagara shale and the Clinton limestone. It was, unquestionably, from some of the beds of the Clinton that the upper gas was largely derived. When the Trenton rock was reached, there were no large accessions to the supply of gas already obtained, nor did the sinking of the well 100 or more feet into the Trenton nor the use of the torpedo improve its yield to any extent. Its flow in August, a month after the well was shot, showed the production to be somewhat less than 10,000 cubic feet per day. Such a result of the

drilling was a serious disappointment to the projectors of the well and to the people of Fremont, this being the first marked failure that had been experienced in the field. The real significance of the facts here found could not be understood at the time, because there were so few facts with which to compare them. It was just this experience, and that of the dozen or more towns that soon followed in the line that made it possible to deduce certain laws or conditions of production in the new territory, that are beginning to prove serviceable in the development of the field.

The first of these laws pertained to the absolute level at which the Trenton limestone was found. As the result of all the drilling that had been done up to June, 1886, it was possible at that time to say, that *the really important gas and oil production was entirely derived from those portions of the Trenton limestone that do not lie more than* 500 *feet below tide-water.* There was no "theory" whatever connected with this conclusion. It was a simple deduction from the facts that had been thus far obtained. The provisional nature of the conclusion was fully recognized, and room was guaranteed to all new facts.

But little modification has been required in this general conclusion. The facts first brought in proved to be truly representative ones, and they have been found to furnish the grounds for a deduction that will remain in its main features as a fixed fact in the geology of the region under consideration.

The elevation above named derives all its importance from the relations that the areas of the Trenton limestone above and below this line hold to each other. There is no known significance in the absolute figures. The large terrace or arch of the Trenton limestone that extends through the counties already described, brings its highest tracts 250 or 300 feet below tide. Whenever a level of 500 feet below tide is reached, the rock is found, if porous, to be saturated with salt-water.

The minor exceptions to the law that have been since discovered all depend on local flexures in the Trenton limestone where it lies more than 500 feet below tide. These flexures, if of large enough extent, have acted in the same way as the main terrace has done in differentiating the gas, oil and salt-water from one another. Several of these folds will be pointed out in subsequent pages. One of some small importance passes through the Fremont district.

Another conclusion of fundamental value in the matter of oil and gas accumulation pertains to the character and composition of the Trenton limestone. The real signifiance and importance of this factor in the productiveness of the rock was recognized at a later period than the law

already named. It can be stated in these words, viz., *the productive portions of the Trenton limestone consist of highly crystalline dolomite or magnesian limestone, containing but a small percentage of impurities.* This law requires some qualifications and admits of a few apparent exceptions at the present time, but it is of wide application and great value in interpreting the behavior of the different portions of the field.

The analysis of the Trenton limestone from the first well at Fremont gave the first important fact in the establishment of this law. The composition of the limestone was found to be as follows, viz.:

Carbonate of lime	75.74
Carbonate of magnesia	13.37
Insoluble matter	6.53
Alumina and oxide of iron	——

This was seen at once to be an entirely different rock from the Findlay and Bowling Green gas-rock. The facts as to its production were also greatly in contrast with the facts derived from those fields, as is seen by the statements given above. There is no reason to count a rock of this composition a gas-rock in any such sense as to warrant drilling to any great depth, or at any great outlay to find it. All these conclusions in regard to it came later, however, when a considerable amount of observation as to the character of the rock had been accumulated.

The gas company was by no means disposed to consider the first failure a condemnation of the territory at large; but it was argued that the main point, viz., the presence of gas in the Trenton limestone was already established, and that it only now remained to find, by drilling, the point where the gas existed in profitable quantities. Other wells were at once begun by the gas company, and presently after by Noble & Co., proprietors of several lime-kilns within the corporation limits, the drilling being undertaken with reference to a supply of gas for lime-burning. All of these wells repeated substantially the history of the first. All showed gas in noticeable quantities in the Clinton horizon, and some of them also produced a small amount from the top of the Trenton limestone. In one of these wells, the last formation was again tested in its lower beds as well, and the drilling was carried to the depth of about 1,500 feet, a depth of 150 feet in the limestone; but the only result was to release a considerable flow of salt-water at the bottom of the hole. In a number of these wells, a small amount of oil of the Findlay type was shown. The gas company has, up to the present date, drilled six wells to the Trenton limestone, and Noble & Co. have drilled three. The largest producer of the first five of the gas company's wells was No. 2. Measured in June, 1886, it was found to produce 18,760 cubic feet of gas per day. This well has been the main reliance for the pipe-

line of the gas company. It shows a rock-pressure of 300 pounds when shut off.

The three remaining wells in this list are all light producers, averaging, probably, less than 5,000 cubic feet per day. The three other deep wells of the town belong to the same grade with those already described, their aggregate production being given as about 30,000 cubic feet per day. A sixth well, drilled in the fall of 1886, by the gas company, has made a somewhat better record. It was drilled in the center of the town, and although upon ground forty-seven feet higher than well No. 1, it found the Trenton at 1,326 feet, or at two feet less depth than the limestone held in the wells above-named. This elevation of the Trenton of forty-nine feet at this point was gained in less than half a mile, and it was not without effect on the production of the rock. The flow of gas was found more vigorous than in any of the wells previously struck. It was computed that this well would yield more than the other five combined that belonged to the company. The gas was found in the uppermost seven to twelve feet in the Trenton, but the company, unwisely, as the event has proved, decided to go deeper, in the hope that the quantity of gas would be increased thereby. No advantage, however, was found, but at thirty-nine feet in the Trenton, a small vein of oil, and a considerable vein of salt-water, were found at one and the same point. The salt-water was in force enough to fill the well, bearing a few feet of thick oil upon its surface. The well began to spray oil and salt-water and the supply of gas was necessarily interfered with. Although much more vigorous than its predecessors, by reason of the advantage it enjoys over them all in the higher level of its limestone reservoir, this well still belongs to the same general class with the rest. There is nothing in its behavior, so far as seen, to warrant the expectation that it would have made, under the most favorable conditions, an adequate source of public gas supply in a town like Fremont. The nine deep wells at Fremont can scarcely be counted valuable as sources of gas from the Trenton limestone. In one point of view, they are somewhat better than downright failures, as they do make some return for the capital invested in them; but on other accounts, it would have been better for the investors to have found no gas at all in their first wells, and they would not then have been lured on to the considerable expenditures thus far made. The gas company has, at present, fifty or more stoves dependent upon its line, but the supply is so lacking in vigor as to be unsatisfactory and disappointing.

The description of the gas-wells of Fremont must not be concluded without an account of the six shallow wells that have been drilled here within the last year, and which, all things considered, are much more

promising than the deep wells by which they are surrounded. It was observed, in drilling the deep wells, that notable supplies of gas were, in all cases, found in the Clinton limestone not far above the red-rock, or the Medina shale; but as the drillers, in going down thus far, were obliged to overcome the main difficulties of the descent, arising from the hard nature of the upper limestones, the waters which they carried, and the casing of the wells, they were naturally unwilling to stop at this point, while 700 feet of shales lay just below, through which the drill could be made to sink at the rate of at least 100 feet per day. From this portion of the drilling, the money must be mainly made, and consequently the supply from the upper horizon was belittled and depreciated to a certain extent. Early in 1886, however, Mr. Geo. O. Harlan, who had been observing closely and sagaciously the progress of the advance thus far, decided to sink a well on his own premises, the special object of which should be to obtain what gas could be got from the upper horizon, below which he did not desire to go. He drilled for himself, employing a portable rig of the Elmira pattern, and found a good supply of gas for home use. The section was as follows:

Drift	10 feet.
Gas found at	445 "
Depth of the well to the top of the red rock	568 "

Other wells rapidly followed, Mr. Harlan having done all the drilling of the shallow wells up to the present time. A well put down for Dr. Ames, in the center of the town, proved the most successful of all this group. It was located in the same elevation of the rocks that well No. 6 found, being separated from the latter by not more than 150 feet. Its daily yield was found, in July 1886, shortly after its completion, to be 16,473 feet per day. The wells are cased in the Niagara shale, which they found at a depth of about 375 feet. They are entirely dry thereafter, if the work is well done. The gas is unmistakably derived from the Clinton limestone, fossiliferous fragments of which are thrown out in the torpedoing of the wells sufficient to establish this determination. The wells require no anchoring, but are cemented about the casing, and have continued, without interruption or trouble of any kind, to the present date. The cost of the wells completed, ranges from $850 to $1,000, and a good well of this type is adequate to supply, perhaps, a half dozen families that are located sufficiently near the well. A well yielding 10,000 feet a day becomes, on such a basis, a profitable investment.

Since the above statements were completed, Fremont has acquired some additional experience in this line, but it all agrees fairly well with that already reported.

A deep well, drilled for Ex-President Hayes at Spiegel Grove, proves to be of small value. Its gas, which is mainly derived from the upper horizon, is inadequate for the supply of the residence. Noble and Company have drilled several deep wells in addition to those already reported, and of the same general character, except that one at least was altogether dry.

Other parties have also drilled in town and in the vicinity with the same unsatisfactory results, with a single exception, to be presently named. Among the wells recently drilled, may be named the Edgerton well, which furnishes a supply for a house; the Starwalt well, which yields nothing; the Board of Trade's well, No. 1, a mile or more east of the town, which obtained a light flow at an unusual depth in the Trenton. The vein is weak, at most promising a supply for a few houses. Accounts differ as to the point from which it was obtained, some assigning it to a depth of 90 feet in the Trenton rock, and others to a depth of 130 feet. The question is not an important one, so far as this well is concerned. There is nothing in it to warrant sinking another well.

A well known as the Muscalunge well, five miles north of Fremont, went 157 feet into the Trenton without result.

The only exception to this record of failures, or of gas supplies that are worse than failures, because of the false promise with which they lure on to greater expenditures, is a well coming in at this date, September 1st, 1887. It is known as the Wagoner well, and is located five miles west of Fremont. It reached the Trenton at 1,274 feet, against 1,326 feet in the Fremont wells, and it seems also to show about fourteen feet of the Findlay oil-rock. Its supply of gas is much better than that of any of the preceding wells as reported. It is twenty-four feet in the Trenton, and the last screw showed the presence of oil, which will need to be shut out by plugging. The casing is 360 feet deep. The Niagara shale is reduced to little more than a mark, but is still recognizable. The flow is variously estimated, many putting it as high as 200,000 feet, others at three or four times this amount, and others still at a half or quarter of the first-named figures.

Another well is to be drilled still further to the eastward on the strength of this improved record.

High-pressure gas from the Bloom township field, Wood county, has already been introduced into Fremont by the North-Western Ohio Natural Gas Company. The outlays already made in piping the town have been utilized, the franchises of the gas company having been turned over to the North-Western Company so as to cover all expenditures. The new company has sealed up the little wells that were included in the sale as of no practical value, and are furnishing an ample supply to the town for manufacturing purposes as well as for domestic use.

The rates adopted by the North-Western Ohio Natural Gas Company are appended here in full as in force in Fostoria and Fremont. The rates of the Tiffin company are identical, and the Toledo rates are based on the same rules.

The following are the monthly charges for fuel gas :

"Domestic Use.

Heating.

	No 7 Mixer.			No. 5 Mixer.			No. 3 Mixer.		
	Monthly charges.	If paid before the 10th.		Monthly charges.	If paid before the 10th.		Monthly charges.	If paid before the 10th.	
		Discount.	Charges.		Discount.	Charges.		Discount.	Charges.
1st Mixer	$4 00	$0 40	$3 60	$3 00	$0 30	$2 70	$2 00	$0 20	$1 80
2d "	3 50	0 35	3 15	2 50	0 25	2 25	1 75	0 17	1 58
3d "	3 00	0 30	2 70	2 00	0 20	1 80	1 50	0 15	1 35
4th "	2 50	0 25	2 25	1 50	0 15	1 35	1 00	0 10	0 90
5th "	2 00	0 20	1 80	1 25	0 12	1 13	0 80	0 05	0 75

"$1.00, gross, per month will be added to the above rates, when mixer is used on double heater.

"Above rates will be charged for the months of November, December, January, February and March. One-half rates for April and October, and $1.00 per month, gross, for May, June, July, August and September.

"Half rates on grates and stoves in rooms heated by boiler or furnace.

Cooking.

From October 1st to May 1st.				From May 1st to October 1st.			
Size of Mixer.	Monthly charges.	If paid before the 10th.		Size of Mixer.	Monthly charges.	If paid before the 10th.	
		Discount.	Charges.			Discount.	Charges.
No. 7	$2 75	$0 25	$2 50	No. 7.....	$2 00	$0 20	$1 80
No. 5	2 00	0 25	1 75	No. 5.....	1 00	0 25	0 75

Laundry.

(When cook stove is also furnished.)

No. 7.....	$1 15	$0 15	$1 00	No. 5.....	$0 80	$0 05	$0 75

STORES, HALLS, ETC.

Heating.

	Monthly charges.	If paid before the 10th.		
		Discount.	Charges.	
1st 500 sq. ft. of floor surface	$3 33	$0 33	$3 00	These rates will be charged for the months of November, December, January, February and March, ½ rates for April and October, and $1.00 per month, gross, for May, June, July, August and September.
Each additional 100 sq. ft.	0 17	0 02	0 15	

HOTELS.

Heating.

	No. 7 Mixer.			No. 5 Mixer.			No. 3 Mixer.		
	Monthly charges.	If paid before the 10th.		Monthly charges.	If paid before the 10th.		Monthly charges.	If paid before the 10th	
		Discount.	Charges.		Discount.	Charges.		Discount.	Charges.
1st Mixer	$4 00	$0 40	$3 60	$3 00	$0 30	$2 70	$2 00	$0 20	$1 80
2d "	3 50	0 35	3 15	2 50	0 25	2 25	1 75	0 17	1 58
3d "	3 00	0 30	2 70	2 00	0 20	1 80	1 50	0 15	1 35
4th, addit'l	2 00	0 20	1 80	1 25	0 12	1 13	1 11	0 11	1 00

COOKING AND LAUNDRY.

No. 7 Mixer.....	$4 00	$0 40	$3 60	No. 5 Mixer...	$3 00	$0 30	$2 70

"Any of the above-named mixers may be used for one or more months, at the option of the consumer.

"In computing rates, the mixers will be taken in order of size, beginning with the largest.

"ANNUAL CONTRACTS, payable quarterly, in advance, may be made on favorable terms upon application at the office.

"The company will make all necessary connections with its street mains, run service pipes and fit up houses complete for use of fuel gas, free of cost to its patrons, except for burners and stove fixtures, which must be paid for by the consumer.

"The mixers are owned by the company, and furnished without charge. Patrons are cautioned against interfering with them in any manner. Any defective service will be promptly attended to, upon notice at the office. A damper in stove pipes is necessary to insure successful service.

"All bills are due on the 1st day of the month, and payable in advance, *at the office of the company.* Ten days' grace is allowed to patrons who pay promptly, but *bills must be paid on or before the 10th of each month to save the discount.* Allowing the time for discount to expire before making payment, does not give an extension of time on the bill.

"Gas is furnished to manufacturers at prices based on the cost of other fuel."

Noble and Company are burning lime in Fremont by gas supplied by the Northwestern Ohio Company, at the rate of 5 cents per barrel of lime, and the initial experience is reported as satisfactory. The cost of fuel at this rate is reduced to at least one-third of the price of wood.

Fremont has acquired two substantial manufacturing enterprises on account of the introduction of natural gas. Both have come in without subsidies or contributions of any sort. They are the Thompson-Houston Electric Light Company, and the Elyria Shear Works. They will make a valuable contribution to the business activity of this prosperous and happily-located town.

Fostoria.

Fostoria made an early and decided trial of the Trenton limestone, and after failure in the first well, repeated the expensive experiment in a second, but without valuable results. In the second well, a small amount of gas was found, but not large enough to warrant utilization for any other than domestic use, and that only in the smallest way. The record of well No. 1, which was drilled mainly in the month of July, 1885, is as follows:

White limestone	250	feet.
Red, irony rock	10	"
Gray-rock, hard	12	"
White-rock, very hard	18	"
Blue-rock, hard	15	"

White-rock, hard	3 feet.
Cased at	309½ "
Blue shale	93 "
Red shale	120 "
Calcareous shale	480 "
Black shale	253 "
Trenton limestone, found at	1253 "
Well finished at	1775 "

The Trenton was found here 471 feet below the sea-level, and with only a slight showing of oil. At this time but little experience had been accumulated as to the practicability of sinking deeper into the Trenton when the top of the rock proved unproductive. Fostoria contributed its share to this experience by drilling more than 500 feet into the limestone without any return of value whatever. At one point, viz., at about 1,450 feet a little gas and oil were found, but the supply was too feeble to admit of profitable use. Salt-water was yielded in small amount at various depths in the Trenton limestone.

The composition of the gas-rock was found to be as follows, viz.:

Carbonate of lime	61.50
Carbonate of magnesia	27.30
Insoluble matter	5.82

The marked departure from the Findlay type of Trenton limestone was first found in this and in the Fremont well already quoted, but it was a long while before the significance of the facts was fully understood. This point has been more fully treated in preceding sections, and will also be considered in other connections.

A second well was drilled in 1886 by J. A. Bradner, Esq., at his lime-kilns west of the town. The gas was sought at this point with reference to use in the burning of lime. This well repeated the history already described, except that it showed a little more gas than the first, though of no more value. In this well there were 250 feet of upper limestones and 945 feet of shales. The Trenton was struck at 1,225 feet, and drilling was continued to 1,400 feet. The well was torpedoed with 333 pounds of nitro-glycerine, between 1,225 and 1,255 feet. For twelve hours after the explosion, the promise seemed good, but the yield of gas soon ran down to less than 10,000 feet per day. It was thought that the well would have yielded four or five barrels of oil to the pump per day, but there was nothing to justify further outlay. Gas and oil, of course, may exist in large accumulations at this point; but in the experience thus far acquired, there are no facts that would serve to indicate their presence or to encourage further expenditures in the search. The gas-

wells drilled at the Godsend water-tank, four miles west of the town, make the nearest approach to the productive territory of Fostoria. These have been described on a preceding page and in another connection.

The Northwestern Ohio Natural Gas Company has introduced gas from its great wells in Bloom and Cass townships to the westward for the domestic use of the town, and the corporation of Fostoria has purchased gas-territory, drilled wells, laid a pipe line, and encircled the entire town with a six-inch line, (nine miles in entire length of line), from which, practically free gas is offered to manufacturers who may locate here, with grants, in several cases, of land and stock subscriptions in addition.

Three important glass factories have already been located and begun within the corporation, viz.:

The Mambourg Window Glass Company.

The Fostoria Glass Company (tableware).

The Butler Art Glass Company.

The village corporation has bonded itself, with legislative permission, for $35,000, for the purposes named above. A company has also been formed of enterprising citizens to aid in this object, the funds of the company ($25,000) being made auxiliary to the work of the town.

The three corporation wells have already found their record in the account of Hancock county production.

Lime is being successfully burned by gas at Fostoria on quite a large scale. An account of this will appear later.

Sandusky.

The drilling for oil and gas under the new interest was begun at Sandusky in the summer of 1886, by the Bay City Natural Gas, Oil and Fuel Supply and Electric Light Company, organized for the purpose of testing the Trenton limestone at this point. The well was located on the west side of the city, near the brewery of Jacob Kuebler. The record of the well is verified by the excellent set of samples preserved by Mr. Kuebler, and kindly furnished for the use of the Survey. The level at which the well was begun is about 585 feet above tide. The Trenton was reached at a depth of 2,210 feet, from which it appears that its upper surface is more than 1,600 feet below tide. The drillers' record is as follows:

Drift	10 feet.
Limestone, in the main, solid	1,050 "
Shales	90 "
Cased at 982.	
Red and blue limestones at 1,050 feet	40 "
Blue shale	50 "
Red shale, beginning at 1,240 feet	160 "
Blue shale	500 "
Dark shale	310 "
Trenton at	2,210 "
Well finished at	2,260 "

The record, as followed by the samples, is full of instructive information. It does not give us the means of resolving the entire column into its constituent parts by sharp boundaries between the several formations, but it furnishes a large number of important and unexpected facts. The upper limestones, which have a thickness of more than 1,000 feet, belong near the summit of the Upper Helderberg limestone (Devonian), and include the whole extent of Upper Silurian limestones, viz., the Lower Helderberg, or Waterlime, the Niagara limestone, the Niagara shale, and the Clinton limestone. This great collection can be approximately divided, in the evidence furnished by the drillings, as follows:

Drift	10 feet.
Upper Helderberg limstone	100 "
Lower Helderberg or Waterlime, and Niagara limestones	970 "
Niagara shale and Clinton formation	105 "
Medina	175 "
Hudson River shale	500 "
Utica shale	310 "
Trenton at	2,210 "

Generalizing once more the facts here given, the section can be stated as follows:

Devonian and Upper Silurian limestones and Niagara and Clinton shales	1,170 feet.
Medina and Hudson River and Utica	1,030 "

Among the unexpected facts shown by the record is the great thickness of the second section of the upper limestones; and furthermore the occurrence of gypsum in very large amount in this section. This mineral is found at fourteen different points in the descent, if the samples can be trusted for this determination; beginning at 110 feet below the surface, it extends through 800 feet of strata. The depths at which the samples indicate its presence are as follows: 110, 275, 320, 425, 500, 525, 550, 575, 625, 640, 725, 750, 800, 825, 925. A bed nine feet thick was reported by the drillers at 275 feet. This was the largest deposit found in any one place. No rock salt was reported in any part

of the well. The drilling was done by contractors from Bradford, Pa., this being their first Ohio well. Casing was attempted early, the first attempt being in a streak of shale found in the limestone at 370 feet. The well was kept dry by this casing down to 960 feet, when a vein of water, rank with sulphur and salt, came in, which required the casing to be drawn. It was finally set at 980 feet. The new resting-place for it was, doubtless, in the Niagara shale, and this stratum proved an efficient cover for all the rocks below. At 1,180 feet the Clinton limestone, with its characteristic fossilferous red and blue beds occurred, but no water was held by it. Neither gas nor oil were found in any considerable amount throughout the descent; and the upper surface of the Trenton also seemed essentially barren, although, at the depth of 2,260 feet, or about fifty feet in the Trenton rock, seven or eight feet of limestone were found saturated with oil. The well was subsequently "shot" at this point with thirty quarts of nitro-glycerine, and it responded by filling up 200 feet with oil, accompanied with a little salt-water; but the pump failed to command a supply for its operations, and was soon abandoned. A little gas appeared at the same time with the oil, and the amount was increased by the use of the torpedo. The daily flow of the gas, as determined by the anemometer, July 3, 1886, was 6,955 cubic feet per day. This gas is now used by Mr. Kuebler in his brewery for light and fuel, and the flow is reported as undiminished at the present date, Aug. 1887. A second well was afterward begun by Mr. Kuebler, the object in drilling which being to secure a supply of water for his brewery, but at a depth of about 300 feet a vein of gas was struck of much greater volume than the gas of the first well. The drilling was arrested at once at this point, and the new vein was united with the former supply.

The economic results of drilling at Sandusky have not been satisfactory, there being no adequate return for the considerable outlay; but the scientific facts furnished by the records are of great interest and of permanent value. They attest the former existence at this point of an enclosed and subsiding upper Silurian sea, in which beds of gypsum were deposited during a period long enough for the formation of 800 feet of stratified rocks. The same line of facts comes to view in several other sections to be hereafter reported.

From the statements here given, it is obvious that the gypsum of northern Ohio is not confined to a single formation, viz., the Salina, as held by Dr. Newberry. The Salina group, at the best, is but doubtfully identified in our geological scale, but gypsum is certainly distributed through the whole thickness of the lower Helderberg, and

possibly through the Niagara also. Gypsum is known to be found in typical Niagara rock at Lockport, New York, as will be remembered.

A comparison of the Sandusky section with one of the deep wells at Cleveland, will presently be instituted, and the two records will be seen to throw light on each other.

The progressive thickening of the shale series, as it was traced eastward, will not fail to command attention as an important geological fact. From the surface of the red-rock, or Medina shale, to the Trenton in the Findlay wells, the interval is 810 feet. At Fostoria the same geological interval measures 853 feet; in Sandusky, 1,035 feet.

Drilling is still continued in the town, a company having recently raised $10,000 to sink three additional wells to the Trenton limestone. None of them have been completed as yet, (Sept. 1887.)

Tiffin.

Tiffin began to drill late in 1885, and reached the Trenton in January, 1886. The well-head is about 744 feet above tide. The upper surface of the Trenton was reached at 1,490 feet, or 746 feet below tide. The history of the well is as follows: It was begun in the lower beds of the Waterlime, twenty or thirty feet of the upper limestone belonging to this series, and the balance to the Niagara. The survey was favored with samples of the drillings, preserved with care by Mr. J. J. Fleck, secretary of the company that undertook the work. The record is here given:

Solid limestone—	
Brown and drab	300 feet.
Dark-blue	40 "
Drab	45 "
Hard limestone	— "
Shales and limestones alternating—	
Blue shale at	450 feet.
Shale and limestone at	480 "
Shales—	
Red rock at	560 feet.
Blue shales at	715 "
Brown and black shales at	1,260 "
Trenton limestone at	1,490 "

The well was drilled to 1,505 feet. A small flow of gas was reached at this depth, and also oil and salt-water. The well was subsequently deepened twenty-five feet, but without result. The oil was lighter than any previously obtained in the Trenton, its gravity being 42 B. This fact was noted with great interest by oil operators. The well was shot, and twenty or thirty barrels of oil were baled out, but when the pump was introduced, there was no answer. A second well, however, was

forthwith projected by the same company that had drilled well No. 1. Work was begun early, but many delays were experienced, and the Trenton was not reached until October, 1886. This well is located about a mile south of the town, and on somewhat higher ground than the first well. The Trenton limestone was found in it at a depth of 1,615 feet, or 125 feet lower than in the first well. Such a disposition of the limestone floor as is thus found in the two wells would have warranted, on the basis of all the experience thus far in hand, the confident conclusion that the second well would probably be filled with salt-water from the start, or that, in any case, the supply of oil would be less than in the first, while little or no gas could be reasonably looked for. These natural and apparently well warranted forecasts were found, in practical experience, to be without foundation. Well No. 2 proved much more vigorous than No. 1 in every way. It has not yet been torpedoed, but the force of the gas is strong enough to lift the oil from the considerable depth reported. Its production thus far has been variously estimated at three to five barrels of light gravity oil per day. The well has been tubed, and the attempt has been made to pump the oil, but without success. The history of the two wells has made quite a strong impression on the practical men who have become acquainted with the facts, and the leasing of territory is going on rapidly and upon a large scale. New wells are already projected, and it is probable that some further attempts to develop the character of the Trenton limestone here will be begun during the winter of 1886. If an oil-field that can pay for working is developed at this point, it will prove a very important fact for northern Ohio, extending the promise or production for many hundreds of square miles beyond the limits that now obtain. The probabilities, however, seem to be thus far on the side of a small and unremunerative production.

Since the above statements were completed, a good deal has been done in Tiffin and its immediate vicinity in the way of exploration for gas and oil. The second well above referred to has been shot, and its volume of oil has been somewhat increased by the operation. It is now said to flow twelve to fifteen barrels per day. The company that drilled it has sold it, and it is now under the control of an individual. Oil has been shipped from this well to Cleveland refineries.

The city council, with the general approval of the citizens, as is understood, has availed itself of the park law, which provides for the appointment of commissioners in towns of this size who shall have charge of the laying out and care of public parks, including the *lighting* of the same at night, and has proceeded to seek its supply of light for this purpose from the Trenton limestone, which lies 1,600 feet below the surface. The commissioners have already drilled two wells, one east

and the other north of town, both of which have proved failures in every sense of the word. They have also located two additional wells, one west and one south of the town, and will drill them forthwith.

Another well has also been sunk here which deserves more particular mention. It is the well of Loomis and Nyman, and is located on the grounds connected with their large machine-shop and manufactory in the heart of the town.

This well was completed in the summer of 1887. The Trenton limestone was reached at a depth of 1,465 feet, or about 725 feet below tide. It is but three-eighths of a mile from well No. 1, and in this interval a difference of twenty-two feet in the elevation of the Trenton limestone is found, the difference being in favor of the later well. The facts of the elevation of the Trenton are still more strikingly shown when comparison are established with the other wells of the field. The facts are stated below. Depths to the Trenton limestone:

Well No. 1	1,490 feet.
" 2	1,615 "
" 3	1,605 "
" 4	1,547 "
" 5	1,465 "

There is a difference in the surface elevations of about forty feet, Nos. 2, 3 and 4 being on higher ground than Nos. 1 and 5, but when full allowance is made for this it is seen that the Trenton shows very discordant structure here, and that the last well, which is almost encircled by the others, has a decided advantage over all in respect to the level of the oil-rock. The well appears to have another and unexpected advantage. The drillers report about ten feet of productive rock, which is unmistakably the Findlay dolomite. This element is certainly more distinct here than in the other wells. In fact it is not known to be found in the rest. Underneath the ten feet of gas-rock the white flaky Trenton limestone of the unproductive sort appeared.

The record, as furnished in general terms by Messrs. Loomis and Nyman, is as follows:

The upper limestones were about 400 feet thick. From 250 feet to 350 feet a succession of chert balls was met that was passed with great difficulty. The Clinton also consisted of a hard and short-grained limestone that made very slow and difficult drillings. The shales below were also quite short-grained and treacherous. The well was drilled with a rig and tools constructed by Messrs. Loomis and Nyman. No derrick was raised, but all the work of the derrick was done by a couple of ladders that can be set in their places in a few minutes. The descent was rapid and successful in every way.

The Medina shale appeared as red rock for about fifty feet.

The Trenton was penetrated for twenty-nine feet, making the depth of the well 1,494 feet. Gas was struck, as already stated, in the uppermost ten feet of the Trenton. The volume is comparatively small, but it proves ample for the supply of a sixty-horse-power boiler. The proprietors deem it adequate for several such boilers.

Measured by the anemometer August 31, 1887, the well was found to produce 61,214 feet in twenty four hours. Unfortunately there is a little sulphurous salt-water at present finding its way into the well. It may drip in through defective casing from the black Utica shale, which, as already stated, is broken or short-grained in the well, or it may be derived from the Trenton limestone. The latter source, if found to be the true one, will detract much of its present value from the well.

A surprising fact as to the closed pressure of the well remains to be given. This little vein accumulates the highest pressure that has ever been reported from an Ohio gas-well. Tested by a reliable gauge, the pressure passes the 600-pound limit of the instrument with a considerable part of its force unrecorded. There is no doubt that it would show 650 pounds, and probably it would register 700 pounds or even more on a gauge that could record these facts. A valve that was easily able to endure the strain of the great Findlay wells burst when it was set to guard this scanty volume over night.

The increase of the pressure when the gas is confined is fairly rapid. It gains when the well is dry about thirty-three pounds in one minute.

The explanation of this unexpected pressure is obviously connected with the depth of the well. It has already been urged that the depth of the well is a factor in the rock-pressure of the gas (see page 100).

The initial rock-pressure of the Bloom township field is said to have been 520 pounds to the inch, and the present rock-pressure, 465 pounds. The first figure, at least, is reported from the Simons well. The latter well shows the surface of the Trenton limestone to be 300 feet below tide. Adding 600 feet to this as the approximate elevation of the nearest outcrops of the Trenton limestone to the northward, we have 900 feet. Treating the Tiffin well in the same way we obtain the figures 1,325 feet. Proportion can be established between these several elements as follows:

900 : 1,325 : : 520 : 765
900 : 1,325 : : 465 : 640

It is probably between these last results that the actual pressure of the well stands.

Whether the suggestions made above as to the cause of the astonishing rock-pressure of the little Tiffin well are correct or not, there is

scarcely room to doubt that the pressure is dependent upon the depth of the gas-rock.

Bloomville.

Bloomville, a small town six miles southeast of Tiffin, undertook the work of drilling early in 1886. Much delay was experienced in sinking the well, the delay resulting from mistaken ideas of the geology of the region, and wrong calculation as to the depth of the limestone stratum. The estimates of the contractors were based upon finding the same state of things at Bloomville as had been found at Findlay, Fostoria, Fremont and Tiffin; but a glance at the geological map shows that Bloomville is located upon the Upper Helderberg limestone, so that nearly the whole thickness of the limestone series of the state must be traversed before reaching the Medina shale. In point of fact, the upper limestones were finished at 840 feet, where the casing was set. The Trenton was found about 1,900 feet below the surface, and drilling was continued to 2,150 feet. The well was entirely dry throughout the lower rock, and is, accordingly, a complete failure.

Marion.

A few wells drilled along the line of the Columbus and Toledo Railroad will next be described. The first of them was located at Marion, where work was quite promptly undertaken after the success of Findlay had been established. The well was begun in June, 1885, and finished in November. It was drilled, as most of the experimental wells have been, by a company of enterprising citizens who could well afford to take the risk involved. The contractor was Mr. A. Coe. The town is located in the western margin of the Upper Helderberg limestone, and consequently, a thicker section of the upper limestones was to be expected in the well than in the northern towns where drilling had previously been done. The well was about 970 feet above tide. The record, as furnished by Mr. Coe, is as follows:

Drift	18 feet.
Upper limestone, with water at various levels	615 "
Blue shale	50 "
Red shale	130 "
Sandstone bearing salt-water	30 "
Blue and brown shales	835 "
Trenton limestone at	1,678 "

The well was continued to 1,790 feet, or 112 feet into the Trenton limestone, when a strong vein of salt-water came in, filling the well and arresting the descent of the tools. No oil or gas whatever were obtained. The surface of the Trenton was a little more than 707 feet below tide.

The sandstone reported below the red-rock must have been of Medina age. This phase is occasionally found in the Ohio wells. A well recently drilled to the Trenton limestone has repeated the record given above in its essential features. Two other wells are projected at this point, for which no justification can be found in present experience.

Upper Sandusky.

A deep well, which was drilled in this town 472 feet into the Trenton limestone, early in 1886, proved a failure. The Trenton was found at a depth of 1,318 feet, or 490 feet below tide-water. It was barren throughout its whole extent, as far as penetrated. A set of drilling-tools was left fast at the bottom of the well. The casing was first set at 180 feet in a streak of shale, but a vein of salt-water that was afterward met, required the casing to be reset at 230 feet. The Medina shale, or red-rock, was struck at 300 feet, and was reported with a thickness of 90 feet. The section obtained in this well was, in all respects, normal. For the facts and for samples illustrating the stratification, the Survey is indebted to the courtesy of Col. S. H. Hunt, who was prominently connected with the company that drilled the well.

The citizens of the place have been unwilling to abandon the hope of proving themselves within the gas belt on the ground of this single failure, and accordingly the corporation has bonded itself to the extent of $10,000, to be used in drilling at least three wells in or around the corporation limits. Two of them have already been completed. Both were located to the west of the town. One found the Trenton at 1,340 feet, and the other at 1,347½ feet. Both are entirely dry.

The composition of the rock has not been determined here, but it is probable that analysis will show it to be of the unproductive sort.

Whartonsburg.

A well has recently been drilled in this village (May, 1887), the location of which seemed to give more geological promise than other portions of the county, inasmuch as the Niagara limestone underlies it. This fact gave the assurance of a higher level of the Trenton limestone than in the wells already reported. The result of drilling did not support this claim to the extent expected. The record of the well, as furnished by Dr. J. Odenbaugh, is as follows:

Drift	48 feet.
White limestone	133 "
Soapstone	200 "
Red shale	68 "
Brown shale	240 "
Black shale	636 "
Trenton, at	1,325 "
Well finished at	1,427 "

The record is easy to interpret, but the division lines would need to be moved somewhat to agree with the geological classification.

The thickening of the shales in this direction is the fact of special interest in the record, the level of the Trenton being kept rather low by reason of this fact. Its surface is about 425 feet below tide. The well was drilled without valuable result. At 18 feet in the Trenton there was a weak indication of oil. The character of the rock is doubtless at fault.

Nevada.

A well has been drilled during the summer of 1887 at the village named above. It was ordered by the corporation. Its record, as furnished by Mr. W. B. Woolley, is as follows:

Upper limestones	600 feet.
Red slate	100 "
Gray slate	800 "
Black slate	263 "
Trenton limestone found at	1,763 "
Well finished at	2,000 "

The Trenton limestone was of the calcareous type already described. It is whitish and fossiliferous, and in this condition rarely, if ever, contains any valuable accumulations. The surface of the Trenton limestone is about 830 feet below tide. The territory seems twice condemned by the two lines of facts. Salt-water was struck before drilling was abandoned.

Carey.

Eleven wells have been drilled at Carey and in its immediate vicinity up to the present time, and several others are to be sunk forthwith. This field has proved somewhat more profitable than those last described, or, in other words, absolute failure is not to be recorded against it. Gas was found in the first two wells in a quantity large enough for utilization in a small way, but the third found but a feeble supply, and even this soon disappeared, so that this well is without any value whatever. The record of well No. 1, as furnished by Baker and Marvin, contractors, is as follows:

Drift	2 feet.
Upper limestones	257 "
Gray slate	65 "
Red rock	52 "
Gray slate	460 "
Black slate	490 "
Trenton (513 feet below tide), at	1,326 "
Well finished at	1,345 "
Gas was found at	1,340 "

Samples of the drillings which were saved, afford, on examination, a slightly different distribution of the shales from that given in the previous record. The Utica shale, for example, can be counted here, as in all the other wells of the region, as 300 feet in thickness. The record, thus adjusted, is as follows:

Drift	2 feet.
Waterlime and Niagara	257 "
Niagara shale and Clinton	65 "
Medina	52 "
Hudson River	650 "
Utica	300 "

The gas appeared in a good flow from the first, and the well was, therefore, not torpedoed. The failure to torpedo is now regarded as a mistake. At a recent date the casing was drawn and a torpedo was exploded in the Trenton. The flow of gas was greatly strengthened thereby, but the gas was no longer dry. The well produced several barrels of oil per day. The oil has since mainly disappeared, and the gas is left in largely increased flow from its former state. The closed pressure, at first, was reported at 335 pounds, but it soon rose to 435 pounds, which is in excess of the rock-pressure at Findlay. The Carey well required an hour to reach its maximum. A measure of its production was obtained in July by the use of the anemometer, and a daily production of 27,163 feet was determined thereby. The second well, which was 1,300 feet west of No. 1, shows an unexpected descent of fifty feet in the series in that direction, the Trenton limestone being found at 1,374 feet, or 560 feet below tide-water. In all other respects, the well duplicated the record of No. 1, as to stratification. There was but small promise in this well when first brought in, the and drilling was, accordingly, continued to 1,428 feet. The well was then torpedoed with thirty quarts of nitroglycerine at the surface of the Trenton, and the flow of gas was greatly improved thereby. In fact, all the force that the gas possessed seemed to be the result of this operation. The flow of gas, measured in July, showed a daily yield of 21,375 feet. The well reached a pressure of 385 pounds in $2\frac{1}{2}$ hours, according to the reports of the company. A fine

flow of gas was found in the Hudson River shale, at a depth of 854 feet, but it blew itself out in about seven days.

Well No. 3, 1,300 feet north of No. 2, was drilled in July, 1886. The surface of the Trenton was found at 1,316 feet, or 498 feet below tide, and the drill was carried to 1,407 feet. The character of the Trenton rock seemed more promising in every way than in either of the other wells, except in the all-important matter of production. It yielded a little gas, but a torpedo of sixty quarts brought no improvement to it and the quantity was altogether insignificant. The record of the last two wells shows the futility of forecasts as to the results of drilling, even in a field as regular as this. The level of the gas-rock is one potent factor in the production of a well; but other factors come into the composition of the problem to such an extent that the risks of drilling would be but little diminished if the strata were all exposed so that their dips and folds could be thoroughly explored and understood before the well was located. The remaining elements would baffle the wisest use that could be made of this first-named factor. The Niagara shale is distinctly shown in this well, in a stratum of fifteen feet in thickness It was not reported, although doubtless present, in the preceding wells.

These wells were drilled by private enterprise. The gas was first used in generating power for the flouring-mills in town. Well No. 1, with its 27,000 feet per day, was not quite equal to the task of furnishing steam for an 80-horse-power engine, but it is probable that the gas was burned at a considerable disadvantage. With well No. 2 thrown into the supply, there was a surplus, which was used in a few stoves and a few lights in the village. The Carey gas seems less offensive than Findlay gas, so far as sulphur compounds are concerned, but it is probable that analysis would show it to have essentially the same composition.

The corporation of the village has recently decided to drill other wells at the expense of the town, to be used in lighting and heating and and in supplying power for other purposes. The work will proceed during the present winter. The town is to be piped under the same system.

Since the preceding paragraphs were written, the corporation has bonded itself for $18 000, and has drilled three wells, all of which have virtually proved failures. The last one gave rise to a strong stream of potable water from the upper limestones, and may pay for itself in this way. The corporation has expended but a small part of the fund at its disposal, and has wisely withdrawn from this unproductive exploration. In the ridge that passes to the north and west of the town, the Niagara limestone comes to the surface. Its appearance as a surface rock is a pledge that the Trenton limestone will be found at less depth than in

the wells which are begun in the adjacent Waterlime territory. The farmers of the ridge neighborhood formed a company in 1887 to test their locality. The first well was put down two and one-half miles north and west of Carey. Its record is as follows:

Elevation of well-head, approximate	850
Drift	14
Cased at	274

Medina shale, quite thick.
Trenton reached at 1,340, or 490 feet below tide.
Well shot with sixty quarts of nitro-glycerine.

Before the use of the torpedo, the flow of gas was very light. Measured May 3, the open pressure in a two-inch pipe at the well-head was two and one-half pounds. This indicates a daily yield of 1,250,000 cubic feet. A remarkable fact in regard to the well remains to be added. When shut in, its pressure rises to fifty pounds almost instantly, but beyond this point it never rises. A maximum closed pressure of sixty pounds is recorded. No other well in the field is known to have a history like this. No explanation is attempted at this time.

Ridge well, No. 2, was of small value. No. 3 was also dry, but No. 4 has proved much the best in the vicinity of Carey. A fifth well, drilled on the ridge by a Carey company, proved dry.

The original gas company has sold out its plant to a new company, in which foreign capital is predominant. This company is piping and supplying the town, and is also making still further proof of the rock at Carey, by putting down two new wells. It is also negotiating for the purchase of the ridge wells, Nos. 1 and 4.

Carey appears to be on the extreme eastern edge of the productive Trenton territory of the Findlay field. There are certain promising features in its structure, as has been revealed by the drill. A rise of fifty feet in a quarter of a mile is an important fact, and further drilling here may show better results than those already found, but it is scarcely to be expected, in view of the large amount already expended within the corporation, that valuable stores of gas are immediately available here. Both of the facts on which production turns seem to condemn the immediate vicinity of Carey. The Trenton limestone is no longer a dolomite, and cannot therefore prove to be a first rate oil rock, and besides this, it lies at or below the dead line of the field.

Carey is, however, fortunate in having gas within easy reach. The ridge wells promise a supply ample for all the demands of the town, present and prospective.

The rates for Carey gas at present are as follows, the contracts running for five years:

Cooking stoves (average for year)	$1.29	per month.
Heating " "	1.58	"
Gas-burners	15	"

Different rates are established for summer and winter. This fact will explain the unusual figures given above.

The Carey wells proper are seen to be of comparatively small account. If the best of them should continue their flow undiminished at their best estate, they would pay interest on the investment and a little more; but the initial cost of the wells would remain in substance charged against them with no provisions for its return to the investors. But if the wells fail within a year, they must become a tax upon their owners for the entire amount expended in them. It is a misfortune to a town to discover gas in such limited quantities as such a supply would prove to be.

Bradner.

In the early part of 1886, a well was drilled at Bradner, a few miles north of Fostoria. The facts, as furnished by John Edmondson, Secretary of the Company, are as follows: The well-head was 193 feet above tide. There was found in drilling:

Drift	20 feet.
Upper limestones	302 "
Shales	880 "

Two bands of red rock were reported, one of thirty and another of twenty feet in thickness, which are probably the uppermost, Clinton, and the lower, Medina, in age. The Trenton was found at 1,222 feet, and was drilled to 1,244 feet. Its upper surface was 529 feet below the tide. The rock showed oil in small amount, but as the well has never been torpedoed, the actual value of the Trenton at this point can scarcely be properly estimated. The town seems to lie a little beyond the outside limit of large production as thus far determined by the record of wells that have been drilled. The practical oil producers evidently see some promise in the record of this well, and will probably make other trials of the Trenton here at an early date.

The chief point of interest in the field lies in the character of the oil. Its gravity was 42° Baumé, and it was thought to be less unfavorably charged with sulphur products than Lima oil. It was believed that it could therefore be refined much more easily and profitably. These facts led Messrs. Ward and Edwards, who had come to Lima to establish a plant at Bradner. They engaged on obtaining an oil supply for small works from wells to be sunk in the immediate vicinity. In this they were disappointed. The first well proved better than any

that followed it, and all can be set down as total failures. The oil agrees in gravity and other characteristics with that of the great wells of the North Baltimore fields, so that the location would have nothing to recommend it even if small wells were possible here.

The refining works established here will be described in another section.

Rising Sun and Pemberville.

Wells have been drilled in both these towns during 1887, but without valuable result. In the first instance a little oil was obtained, in the second, nothing. The records of the wells have not been secured. There is nothing in either out of the ordinary line of facts. The character of the oil from the Rising Sun well is reported good. The capacity of the well was counted 15 to 20 barrels per day by some observers, but the estimate is doubtless too generous. The Pemberville well was drilled 300 feet into the Trenton limestone and was shot, but proved entirely dry.

Toledo.

The interest of a city like Toledo in natural gas is apparent. The enterprise of her citizens instituted the proper test of the new horizon at an early date. The Toledo Rolling-Mill Company sunk a well to the Trenton in October, 1885, and presently afterward a second well. The record of the first, as furnished by T. H. Walbridge, Esq., is as follows:

Drift clay	110 feet.
Upper limestones	454 "
Gas at	665 "
Shales	834 "
Trenton limestone found at 1,398 feet, or about 800 feet below the sea-level.	
Well finished at	1,423 feet.
Salt-water came in at this point.	

The well was afterward torpedoed at 1,398 feet, with 275 pounds of rackrock, and at 665 feet with seventy-five pounds. A feeble flow of gas was secured thereby, amounting to about 7,000 feet per day. The second well was of much the same character. It was drilled to 1,500 feet in depth, but it made no return whatever.

J. H. Hiett and Son drilled a third Toledo well, at the Air Line Junction west of the city. The record is as follows:

Clay	80 feet.
Sand and gravel	40 "
Upper limestones	465 "
Blue slate	5 "
Stray lime rock	150 "
Slate and shale	685 "

The "stray lime rock" of the driller probably includes the lower beds of the Clinton and the uppermost of the Hudson River, with the intervening Medina shale. The Trenton was struck at 1,415 feet. A small volume of gas and oil was obtained at 700 feet, or near the top of the Hudson River series, but the Trenton was unproductive.

A fourth well has been drilled during the summer of 1887 at Point Place, below the city, from the behavior of which, short-lived hopes were raised of a home supply of gas for Toledo. Quite a volume of gas was developed after shooting the well, but it was soon drowned out by the ever-present floods of salt-water. It found the Trenton at a consisiderably lower level than the other wells, according to report.

With this failure, and with the advent of two pipe lines brought in from the great gas-field of Bloom township, Wood county, the search for natural gas at Toledo will probably be abandoned. The pipe lines will be described in another connection.

A well was drilled in 1885, at South Toledo, by Mr. C. B. Orvis, for the village corporation. It is said that a fair volume of gas was obtained here, but the title to the well became involved, and was referred to the courts for a decision, which has not yet been reached. The well agrees in the general section with the three already reported for Toledo, but the Trenton was nearly seventy feet higher here than in the city wells. A well is now being drilled in Perrysburgh, the record of which will reinforce or correct the conclusions drawn from those already described.

The results of drilling at a few points east of Toledo will next be given. Oak Harbor, Port Clinton, La Carne and Rocky Ridge, Elmore, Genoa and Lindsey and Woodville, Gibsonburg and Burgoon are on this list. The first six are situated on branches of the Lake Shore Railway, and the last two on the Northwestern Ohio Railway.

The persistency with which Ottawa and Sandusky counties have been tried by the drill is due to the fact that they lie on the northeast line from the developed oil and gas-fields. Pennsylvania experience has so impressed this line on the driller's mind that he unhesitatingly applies it to every field. It is a superstition when applied to this part of Ohio, as the practical men are slowly learning at great cost to themselves.

Oak Harbor.

The Natural Gas Company, of Oak Harbor, brought in a trial well drilled to the Trenton on July 5, 1886. The well-head is 576 feet above tide. The record is as follows:

Drift	39 feet.
Upper limestones	371 "
Cased at	410 "
Gas (apparently in the Clinton) at	547 "
Red rock	150 "
Hudson River and Medina shales	740 "
Trenton 724 feet below tide at	1,300 "

Gas was found at 1,303 feet in the Trenton, and continued to increase to 1,316 feet. The well was carried to 1,335 feet. A small quantity of oil of 38½ gravity was also produced with the gas, and the inevitable salt-water was found at the same horizon. The oil does not at present amount to more than one barrel per month. It was raised with the gas. The well was torpedoed at both productive horizons, at the lower, or Trenton, with sixty quarts of nitro-glycerine, and in the Clinton with ten quarts. The closed pressure rose, after the well was completed, to 101 pounds in forty minutes. The yield of gas at the same date, as shown by the anemometer, was 78,250 cubic feet per day. Arrangements were at once made to utilize the gas for power in the mill adjoining the well, and for heating and lighting. The flow is said to be maintained without apparent diminution. If it continues on the same scale for a few months longer, the well will have paid for itself. The experience of Oak Harbor is interesting and important in this respect, as showing the smallest yield of gas that has been made really profitable in dollars and cents to the parties that drilled the well.

A second well was not as fortunate as the first. The Trenton was found at 1,326 feet, or twenty-six feet lower than in well No. 1, but still it made a fair showing of dry gas. The fear of salt-water arrested the drilling before the possibilities of gas were exhausted. After being torpedoed with sixty quarts of nitroglycerine in the Trenton, the well filled rapidly with salt-water, which the gas had not energy enough to expel. After the well was pumped, the gas slowly returned, the pressure rising to twenty pounds in forty minutes. This well appears to be practically a failure, its best yield probably falling short of 20,000 cubic feet. The two together are made at present to supply fifty-four stoves and fifty-six lights, which bring in $1,100 per annum. The surplus is used in the mill at the rate of $30 per month for a full supply, which cannot, however, be furnished. The oil that appears with the gas is carried direct to the mill furnace, and is there used. (Aug. 1886.)

The third well that was drilled late in 1886, is located on the south side of the river. It proved far more vigorous than well No. 1. It is not known to have been measured, but it is commonly estimated as producing 200,000 or more feet of gas in a day. It is the main reliance of the pipe line, but it fails to provide a full supply for the demand, and the fourth well is now being drilled in the vicinity of No. 3.

Oak Harbor furnishes the only important exception thus far on record to the first law as to the limits of production, viz., that which makes the dead line 500 feet below sea-level. The explanation of the exception is obvious. In fact, the geological map of Winchell foreshadowed it, a dozen years ago. There is an uplift or fold of the strata passing through Oak Harbor.

It is part of the bifurcated axis that Winchell pointed out in his report on Ottawa county, in Volume II, Geology of Ohio. The Niagara limestone comes to the surface here in an unexpected way, after having sunk from the Genoa ridge below the Waterlime. It is quite unlikely, however, that it occupies as large an area as is represented on Winchell's map. The larger part of this territory must be added to the Waterlime.

The gas supply found at Oak Harbor is the only gas or oil from the new horizon that has not cost more than it comes to when obtained from a greater depth than 500 feet below sea-level. It is not a large supply, but it appears to be economically valuable. Still it must be recognized that production here turns on a narrow margin.

The first well was drilled a trifle too deep, as it was counted, and produces oil and salt-water as well as gas; the second was drilled a trifle too shallow, and was a failure.

Elmore.

Two deep wells have been drilled in Elmore within the last year, the first by Mr. C. Metz, proprietor of the Elmore flouring mill, and the second by the Elmore Gas and Oil Company. The surface of the ground where the wells are located is 658 feet above tide. No accurate record was obtained of well No. 1, but the series appears to have been normal in all respects. Two red bands were found, as in several other wells already reported, one in the Clinton and one in the Medina horizon. The Trenton limestone was a little more than 1,250 feet deep, or about 600 feet below sea-level. The Trenton was dry when it was reached, and the record was the same after the well was twice torpedoed.

A better record of the second well was obtained. It is as follows:

Drift	42 feet.
Upper limestone	410 "
Red shale	50 "
Gray shale, Brown shale, and "soapstone"	803½ "
Depth of Trenton	1,263½ feet.

When the Trenton was first struck, a small quantity of oil appeared. The well was then torpedoed with seventy quarts of nitro-glycerine, and tubed for pumping. It lay for a week after the shot, and then yielded to the pump about thirty barrels of oil of thirty-three degrees gravity, but the oil had stood exposed in the tank for a number of days, so that this determination is scarcely fair. The pump ceased to deliver oil with the first thirty barrels. It was thought to be stopped with sand. Since the remarkable developments of the Lima oil-field, all of these indications of new oil-territory have been carefully noted by producers, and much interest seems to be taken in the Elmore development. Territory has already been leased here upon a large scale. Further and decisive tests will soon be made of the character of the Trenton as a source of oil in this locality. (The results of the tests above referred to are not such as to afford encouragement to expect any large or valuable supplies of oil or gas from this region. Sept. 1887.)

Port Clinton.

Port Clinton, the county seat of Ottawa county, followed the prevailing fashion and drilled a deep well in the winter of 1886–7. Its record, as deduced from samples kindly furnished by S. Motley, Esq., is as follows:

	Feet.
Drift	48
Lower Helderberg limestone (containing gypsum beds at 90, 190)	250
Niagara limestone	200
Niagara shale	50
Clinton limestone	150
Medina shale	50
Hudson River shale	450
Utica shale	360
Trenton limestone	67

The Trenton limestone was reached, as the record shows, at a depth of 1,660 feet, or about 1,079 feet below tide. It was entirely unproductive. The strata are seen to be dipping rather rapidly to the eastward, the descent of the Trenton from Oak Harbor to this point being nearly 350 feet. The distance is 11 miles, and the rate is thus seen to be a little more than 30 feet to the mile.

La Carne.

A well was drilled here in the fall of 1886, the record of which was not made public, in detail. The drift is said to have been 100 feet thick, and the Trenton limestone was found between 1,600 and 1,700 feet below the surface. Nothing of value was found in the well, unless the strong stream of water from the upper limestones shall be so counted.

A well is being drilled at Rocky Ridge at the present time, which will doubtless repeat the monotonous record of failure, or light production, which is often worse than failure. The Trenton limestone has been followed to the eastward until its composition is changed, and it is no longer an oil or gas-rock in any worthy sense of the word.

Genoa.

The results of the drilling done in this town in May, 1887, were kept secret by the company that did the work, for a while at least, and no full record of the well can be given. The following facts were kindly furnished by Wm. Humlong, Esq.:

The well was cased at 440 and the Trenton limestone was struck at 1,292, or 660 feet below tide, Gas was found at 520, 820, 1,303 and 1,308 feet. The well was shot with 40 quarts of nitroglycerine, and the gas flow was estimated to have been increased one third thereby. Oil also appeared with the gas. The supply of both is probably small, but the gas, as might be expected from the considerable depth at which it was struck, has quite high pressure.

Lindsey.

In the village of Lindsey, two wells have been recently drilled to the Trenton limestone. This rock was struck at somewhat less than 1,300 feet below the surface. The first well showed a little gas and oil with a good deal of salt-water. The second produced salt-water pure and simple, filling up within 25 feet of the surface. The great supply was struck at 70 feet in the Trenton limestone.

Woodville.

The village of Woodville produces a lime of excellent character and reputation. To provide cheaper fuel for burning the stone was a main aim of a test-well put down to the Trenton at this point early in 1886. The elevation of the well-head is about 668 feet above tide. The Trenton was struck at 1,184 feet. Its upper surface is thus seen to be 586 feet below tide. The upper limestone ends at about 390 feet, the casing being set at 394 feet. There were 160 feet of red rock, or Medina

shale. Salt-water in small quantity was struck in the uppermost beds of the Trenton. The well was carried down to 1,460 feet without a sign of oil or gas, and at that depth a flow of salt-water was unlocked that filled the well and made further progress altogether impracticable.

Gibsonburg and Burgoon.

Trials of the Trenton limestone have been made in both of these towns during the present year. In the latter case a little gas was found in the Trenton limestone, but a descent of 150 feet into this stratum failed to make any additions to the insignificant amount that was first obtained.

Clyde.

Drilling was begun in Clyde in the summer of 1886. Great difficulty was experienced in getting through the heavy beds of drift at the point where the well was first located. Two contractors successively undertook the work, but quick sand and bowlders prevented either from reaching bed-rock. The drift was more than 130 feet thick at this point, and its composition made it peculiarly difficult to pass.

A new location was made, and the third contractor found the bed-rock at fifty-seven feet. The first rock struck was the Waterlime, 170 feet of which were loose and shelly, making the drilling slow and troublesome. Underneath these beds, gypsum, gray limestone, white limestone and blue limestone were found in succession. The Niagara shale was well represented in thirty feet of fine greenish "soapstone."

The Trenton limestone was reached at 1750 feet, or about 1070 feet below tide. The drilling was continued 100 feet into the Trenton without result. The Trenton limestone holds the same depth below the sea in this well that it has at Port Clinton, which is due north of Clyde. The contour lines of the Trenton have before been found to follow a north and south direction in this part of the state.

Bellevue and Green Springs.

The adjoining towns above named have both made attempts to reach the Trenton limestone within the past year, or are now engaged in sinking to the new horizon. Their geological conditions are similar, except that Bellevue has a somewhat longer section of the upper limestone than Green Springs.

The Bellevue well was begun at an elevation of 747 feet above tide, and in the upper beds of the Upper Helderberg, or Devonian limestone. Rock was struck at seventeen feet. The Upper limestone proved to be 1,000

feet thick. For carefully kept samples of this interesting series the Survey is indebted to Hon. Peter Brady, ex-Treasurer of the State. There was "red rock" for 250, as reported, but it is possible that both the Clinton and the Medina are included under this measure. The drilling was very slow and troublesome. The rocks of this region are much disturbed in structure, and the tools were continually following crevices into forbidden paths. The work has been suspended here, temporarily, at least, at the depth of 1,700 feet, the bottom of the well now being in the Hudson River shale. The Trenton would be due here at about 2,150 feet, or at about 1,400 feet below tide.

A second trial is now in progress at this point, but the results of it are not at hand.

In the brief review that has now been made those wells have been described that have been drilled to the Trenton limestone under the new interest in territory lying east of Findlay and Toledo, and that are located within the outcrops of the limestone series of the state. The list is by no means complete, but all the facts that are of economic interest or importance, that have come to hand, have been stated. All the additions to be made to the list already given, would only be additional failures.

A few wells remain to be described that are located in the outcrop either of the Ohio shale or Waverly group, to the eastward of those already catalogued. These wells will be treated on a subsequent page. The remaining wells of Wood, Hancock and Allen counties, and the wells of Hardin county will next be described. The first section will comprise those that are located along the line of the Lake Erie and Western Railway between Fremont and Lima.

Beaver Dam, Bluffton, Cannonsburg, Rawson, and Mt. Cory.

The well drilled at Beaver Dam was among the first test-wells of the Trenton Rock Oil Company. It was located on the northeast line that was believed, in the beginning of operations here, to lead to fortune. The Trenton limestone was found at 1,309 feet, or at a depth of 445 feet below tide water. The rock contained both oil and salt-water. It was abandoned without being torpedoed, and leases dependent upon it were given up. Certain developments in the Lima field have raised the question, whether it was not too hastily abandoned. There are some who believe that possibilities for productive territory are still to be found in this entire vicinity.

Two wells drilled five miles east of Beaver Dam, in Orange township, Hancock county, in September and October, 1886, may be recorded

here. The Trenton limestone was found 424 feet and 426 feet below tide, but higher by fifty to sixty feet than in the wells that surround them on several sides. The rise toward this point is most marked on the southeast and north, and least conspicuous to the westward. The wells proved to be gas-wells of moderate value. Measured September 25, 1886, the first well was yielding 172,224 cubic feet per day. Two or three such wells that maintained their flow would give volume enough to warrant piping the towns near by, that would eagerly utilize the supply. These wells are known as the Motter and the Charles wells, and were drilled for J. B. Townsend and others, of Lima.

Bluffton drilled in May, 1886. The territory had been leased for some time by oil operators, but it remained for the citizens to make the test of this neighborhood. A company was formed and $1,500 raised in $20 shares. The Trenton limestone was reached at the depth of 1,296 feet, or about 460 feet below tide water. The record, as furnished by A. D. Lugibihl, Esq., and as confirmed by samples of drillings kindly furnished by him, is as follows, the divisions of the rock being based upon the drillings above named:

Drift	5 feet.
Waterlime	200 "
Niagara and Clinton limestones	225 "
Medina, green shale, "gravel and sand"	47 "
Hudson River, or green shale	500 "
Utica or black shale	320 "
Trenton at	1,297 "
Well finished at	1,328 "

The well showed the presence of oil in small quantity as soon as the limestone was reached. Gas also was found in small amount, but with the oil and gas came salt-water. The well was shot, and forthwith began to fill with salt-water and oil. For a little time the entire column was credited to oil, but on pumping the salt-water soon asserted itself, and the well was necessarily abandoned.

Several wells have been drilled at Cannonsburg, a few miles southeast of Bluffton. The first of the series was put down in May, 1886, by the Interior Oil Company, on the farm of John Marshall. The Trenton limestone was reached at a depth of 1,300 feet, or about 450 feet below tide-water. Oil accompanied by gas was found in large quantity at the depth of a foot or two in the Trenton, and the column was thrown by the released gas many feet above the derrick. For a day or two the well flowed through the tubing. The pump was then introduced, and a record of forty-five barrels daily production was made for a number of

weeks, when the well fell to fifteen barrels where it now is. A pipe line was laid to the railroad, but the production was too small to justify its maintenance and it has been taken up. Salt-water has been produced in large quantity from the beginning. The well has not been shot. Two other wells drilled at Cannonsburg were unproductive.

Two miles west of Cannonsburg, on the line of the Narrow-gauge Railroad, three other wells have been drilled. The Reddick well is counted a twenty-five-barrel well, and the Williamson well is also producing oil, but the Dewese well is reported to be of no value.

Other wells have been added to the lists since the statements above made were prepared, but they have not changed the situation so far as the promise of production is concerned. The fact that a northeast line from Findlay to Lima passes through this region, makes the drillers loth to abandon this belt. But nothing has yet been found to repay this wide-spread exploration of the interval.

Wells have also been drilled at Rawson and Mt. Cory; and at both of these points they have proved failures, neither gas nor oil being found, but large quantities of salt-water instead. Rawson struck the Trenton at 1,337 feet, or 516 feet below tide.

Arcadia.

A well drilled at Arcadia, on the lines of the Lake Erie and Western and the Nickel-Plate Railways, in June, 1887, gave the following record, as furnished by Mr. H. N. King:

Drift	55 feet.
Limestones	290 "
Shales	831 "
Trenton struck at	1,176 "
Well finished at	1,365 "

The surface of the Trenton limestone is 370 feet below tide, a level which is consistent with the best production, but the yield of the well was comparatively small. After being shot with forty quarts of nitroglycerine, it is claimed that there is gas enough to supply the town, but no measurements are reported and the well is counted a light one. Gas was first found at four feet in the Trenton, and the amount increased for twenty feet. The company that were putting down the well stopped drilling at 1,274, or 100 feet in the Trenton limestone, but the citizens counted the test unsatisfactory and continued the drilling to 1,365 feet. The depth reached by the company covered every case of production yet recorded in this horizon so far as depth is concerned, and all of the gas obtained came from the first twenty feet of the Trenton limestone.

The composition of the rock fully accounts for its small production. It is as follows:—(*Clarke*).

Carbonate of lime	84.23
Carbonate of magnesia	5.44
Insoluble matter	8.56
Total	98.23

It is seen that in passing from Findlay, ten miles to the southwest, the character of the limestone has been entirely changed. The Arcadia rock is not in any sense the Findlay gas-rock. It is becoming apparent, however, that the changes of composition, such as are described, also occur in the very heart of the productive territory. City Well No. 3, Findlay, on the east side of the town, shows a character of rock of the same character as the Arcadia Trenton. Its production, which is very small, matches also to the composition.

Mt. Blanchard and Arlington.

On the Narrow-gauge Road, between Bluffton and Carey, three or more wells have been drilled to the Trenton; one at Arlington and several at Mt. Blanchard. Mt. Blanchard began to drill late in 1885, and reached the Trenton in January, 1886. A moderate flow of gas and a little oil were found in the rock at this place. An estimate of 50,000 cubic feet of gas per day was made by the driller, but the well does not hold out to these figures. A second well drilled subsequently was not as good as the first, but was practically of no value. Other wells have since been drilled here without materially changing the situation reported above. The last well is counted the best in the field. The gas has been utilized in a small way from the first. The gas production here is thus seen to be similar in value to that of Carey.

Arlington, lying ten miles due south of Findlay, began to drill early, but was a long while in reaching the gas-rock. The rock, when reached, was not found productive. A condensed record is given below: The approximate elevation of the well was 860 feet. The upper limestones continued to 387 feet, where the casing was set. The red rock, or Medina shale was thirty feet thick. Trenton was struck at 1,292 feet, or 432 feet below tide. At 1,304 feet a little oil and gas were found, but not enough to be of value.

McComb.

The village of McComb sunk a well to the Trenton in 1885, but found nothing but salt-water in the rock. The well was drilled by W. M. Martin. The record of the well is appended:

Elevation of well-head	780 feet.
Drift	62 "
Upper limestone	567 "
Casing set at	630 "
Red rock struck at	660 "
Trenton at	1,412 "
Well finished at	1,455 "

In salt-water.

A well recently drilled has proved somewhat more successful, yielding at the present time a moderate volume of gas.

A well drilled at Deweyville also proved a failure. The oil-rock was found at too low a level, as in McComb. The Trenton limestone here is about 630 feet below tide.

Vanlue.

A well, drilled in the fall of 1886, in the village of Vanlue, furnished a small but valued supply of gas for the town. The well was cased at 214. The shale series was 1,050 feet thick, and the Trenton was struck at 1,294 feet, or 471 feet below tide. Drilling was continued in it, in the hope of obtaining a larger volume of gas until salt-water was touched. The amount of daily production is estimated at less than 50,000 feeet, by some who observed its initial flow. By others, it is rated larger.

The character of the Trenton limestone is undoubtedly at fault, so far as the possibilities of large production are concerned.

Ada, Lafayette, Westminster and West Newton.

The first two of these towns are on the Pittsburgh, Fort Wayne and Chicago Railway, the last on the Chicago and Atlantic Railway. A deep well was drilled at Ada early in 1886. The record was as follows:

Elevation of well-head	955 feet.
Trenton reached at	1,433 "

Or 478 feet below tide.

Neither gas nor oil were found in any promising quantity, nor did the torpedo improve the situation. The well was drilled to 1,820 feet, which was 387 feet into the Trenton formation, before being abandoned. A strong flow of salt-water came in at the last.

An unproductive well was also drilled at Lafayette in the summer of 1886. This, and the location next to be named, are really on the border of the Lima field, and are of interest and importance in this connection, indicating, as they serve to do to some extent, the eastern boundary of productive territory.

The Westminster well was drilled at about the same time as the one last named. The elevation of the surface was approximately 1,000 feet. The Trenton was found at 1,368 feet, or 368 feet below tide. It was drilled to 1,400 feet. No value whatever was found in it. A change in the character of the Trenton limestone appears to set in promptly as it is followed southward from the field of present production.

A well, drilled at West Newton in the summer of 1887, was thought to have, from its location, a better chance as a source of dry gas than its neighbors had found. The Niagara limestone was represented in Winchell's map of Allen county, as occupying this territory, but the reference proved incorrect. Such an error in this drift-covered region is not to be wondered at. The only ground for surprise is that Professor Winchell was able to indicate the underlying rocks as correctly as he did. Most of his references are fully sustained by recent developments.

The West Newton well was drilled by the Trenton Rock Oil Company. The casing stands at 450 feet, which is the same thing as saying that it was begun in the Waterlime. The Trenton was struck at 1,440 or 394 feet below tide. The elevation was not at all what was looked for, but no elevation would have given productive power to the hard and close Trenton limestone that was found here. There was no "oil-sand" or dolomite whatever.

This location was one that was suggested to the operators from the discovery made by the Geological Survey that all the gas-wells belong to outcrops of the Niagara limestone and all the oil-wells to the Waterlime.

Kenton.

Kenton, the thriving county seat of Hardin county, has made two tests of the Trenton limestone within its limits and in tributary territory, in the hope of obtaining like success with its fortunate neighbors. Both of these tests have shown the limestone barren of oil and gas in profitable quantity at the points where it was struck. The first well was drilled by the Paper Mill Company at their works, where a supply of gas or oil to be used in power would have been of very great service. The drilling was done in the spring of 1886. The elevation of the casing is about 990 feet. The record is as follows:

Drift	24 feet.
Upper limestones approximately	376 "
Casing at about	400 "
Gray and red shale, Medina	50 "
Blue shale and black shale	1,075 "
Trenton limestone found at	1,550 "
(560 feet below tide.)	
Well finished at	1,600 "

The rock was entirely dry.

The next well drilled in the interest of Kenton was located several miles to the westward, at the extremity of the Scioto Marsh, where "surface indications" of gas were thought to give promise of a more favorable result than that obtained in well No. 1. It was brought in early in October, 1886. A little oil was found in the Trenton, as is so generally the case. The well was torpedoed without effect, and was presently abandoned as entirely valueless. For the facts pertaining to these wells, the Survey is indebted to Dr. J. A. Rogers, of Kenton.

The later experience of Kenton remains to be described. The town was situated too near Findlay and Lima to rest easy and unconcerned while such remarkable developments were going forward in them. Accordingly one well after another was located and drilled in the surrounding territory under the control of the business interests of Kenton. Sagacious management has divided the burdens of the work with the several neighborhoods in which the drilling has been done. A dozen or more wells have now been put down under this system.

From the results of the first experience, it is seen that in the immediate vicinity of the town, the Trenton limestone lies below its dead line for this region. After several additional wells had confirmed this conclusion, it was suggested to the representatives of the Kenton interest that if they insisted on drilling more wells they should consult geological probabilities by locating their next wells on a spur of Niagara limestone that Winchell's map represents as traversing the northeastern corner of the county. The locality was visited, the reference to the Niagara limestone abundantly confirmed, and a well was put down which justified, in all particulars, except the all-important one of production, the geological forecast.

The well was located on the McVitty farm, Jackson township, two miles south of the village of Patterson.

	4 feet.
The surface deposits occupied	131 "
Niagara limestone	35 "
" shale	30 "
Clinton limestone	33 "
White slate, red slate, Medina	252 "
Well cased at	567 "
Hudson River shales	427 "
Utica shale	1227 "
Trenton struck at	1330 "
Well finished at	

In the last preceding well, viz., on the Merriman farm, 371 feet of casing were called for, while here 252 feet sufficed, showing the new location to have 119 feet the advantage in this respect. An equal, or

even greater advantage, was found for the Trenton limestone which had risen from 550 feet below tide to about 275 feet below tide.

Gas came in from the Clinton horizon with strong flow, but a great volume of water was found above it, from which it cannot well be freed. At 835 feet also, quite a volume of gas was obtained. The highest expectations were accordingly awakened as to the Trenton limestone when it should be reached. These expectations were doomed to disappointment. The Trenton limestone proved hard and obdurate to an extreme degree, and showed no approach whatever to the character of an oil-rock. It was shot with sixty-five quarts, but without result.

This well, though a failure, seemed to point the way to possible success. The next well was located two miles west on the McElree farm. It was recognized that the Waterlime made the surface rock, but the Niagara limestone was not far away to the eastward.

The casing stands at 455 feet, but could have been set 100 feet higher. The Trenton limestone was struck at 1,300 feet, or at about 375 feet below tide.

In descending through the upper limestones an enormous flow of water was released, which required a great deal of skill and outlay to control. It is one of the largest streams that has been struck in the state. The unwatering of the rock, which is going forward in this way, is a matter of grave importance and will lead to a serious interruption of the water supply of entire neighborhoods if allowed to go on without limit.

Neither the Clinton nor the shales furnished gas in notable quantity, but the Trenton rewarded the search with a flow that has been estimated by good observers at 200,000 feet per day. This is quite as much as could be expected from rock of the character that was found here. It is the Trenton limestone, but not the Findlay gas-rock. Its composition is shown in the following analysis (*Clarke*):

Carbonate of lime	84.32
Carbonate of magnesia	8.43
Insoluble matter	5.26
Oxide of iron and alumina	1.10
Total	99.11

Kenton has escaped from one limitation, viz., the 500-foot dead line, to find another even more inexorable, in her way, viz., the limitation that arises from lack of the proper chemical composition of the Trenton limestone. This fact has only recently been determined.

A well lately drilled between the two last named is reported as wholly unproductive.

Dunkirk.

Two wells have been recently drilled here, which take their places in the long column of failures already reported.

The Trenton was found in the first at 1,377 feet, or 437 feet below tide. A little gas was obtained at 1,390 feet. Drilling was continued to 1,865 feet, or 488 feet into the Trenton series, where a flood of salt-water was struck, which filled up 1,420 feet of the well. The Trenton was shot with 120 quarts, and the flow of gas was temporarily increased.

Forest.

The well drilled at Forest had some warrant from the geological map for expecting a higher level of the Trenton limestone than had been found in many adjoining wells. On this ground, however, a location one mile to the westward would have appeared somewhat more promising. The record, as furnished by W. B. Bowman, Esq., is as follows:

Drift	69 feet.
Waterlime	78 "
Trenton limestone struck at 1,370 feet—432 feet below tide.	
Well finished at	1,470 "

The rock was entirely unproductive.

THE WOOD COUNTY GAS AND OIL FIELDS.

The large and important series of gas and oil-wells that lie between Findlay and Bowling Green within the limits of Wood county, are next to be described. Before taking up these fields, however, the records of a few wells that lie outside of both gas and oil, as proved by exploration, but which are included within the county limits above named, will be given.

Weston.

Weston, lying about seven miles west of Bowling Green, was loth to believe that the rich stores of power that her neighbors had obtained were locked against her. Failing in one experimental well, she essayed to drill another, the results of which, however, were no more encouraging. The drilling was begun by the Weston Natural Gas Company, in January, 1886. An unexpected and surprising descent of the entire series to the westward was first made known to the drillers by the excessive thickness of the upper limestones, which it cost much trouble to penetrate. The

well was brought in during March, 1886. The record, as furnished by E. H. Bagaley, Esq., Secretary of the Company, was as follows:

Drift	70 feet.
Upper limestone	642 "
Shales	838 "
Trenton at	1,550 "
The casing was set at	712 "
Bitter water was struck in quantity at	788 "
Gas was found at	1,571 "
Salt-water and oil came in together at	1,575 "

Strong veins of sulphur-water were found in the upper limestone from 300 to 400 feet in depth. Weston is 666 feet above tide, and the surface of the Trenton is 884 feet below. The well was shot, and forthwith filled with water, covered by 100 feet or more of oil. The oil had a gravity of 34° B., but as it had been exposed for some time before being tested, the record is of no great value in this particular. It is probably at its best, an oil of lower gravity than Findlay or Lima oil. The entire quantity brought out by the bailer was fifteen or twenty barrels. The second well repeated the record already given in its essential features. It was as follows:

Drift	70 feet.
Upper limestone	620 "
Casing set at	696 "
Red rock, nearly	100 "

The flow of water struck in the upper limestones was even more vigorous from the second well than from the first. In the latter case, the water was quite highly sulphuretted. It flowed from the casing in a strong stream, and held its way in the open ditches in quantity large enough to furnish an important supply of stock-water for several miles.

Haskins.

A well drilled at this point, Sept. 1887, found the Trenton limestone much higher than at Weston. The strata seemed to be affected by the uplift that has been described in preceding pages under the name of the Findlay break, and which has been found so influential in the production of oil and gas in Hancock and Wood counties.

The well has not yet been completed, drilling having been arrested before the Trenton limestone was penetrated many feet, and very different estimates can be had as to its capacity. It serves to indicate an oil-field west of Bowling Green.

Two or three wells drilled in Lucas county will also be described in this connection.

Waterville.

This place seems to be, without doubt, on the line of disturbance and uplift that extends northward from Findlay to the Michigan line. A well drilled here in the summer of 1887 has aroused considerable interest, from the promise it seems to hold out of valuable supplies of gas in the neighborhood.

Well No. 1, located on the Ballou farm, one-half mile east of the town, has the following record:

The casing stands at 273 feet, and the Trenton limestone was struck at 1,125 feet. At 1,132 feet the first gas was struck. The flow increased to 1,153 feet. The well was shot and the flow greatly improved. No measurement has been made of the well, and the estimates of the volume of gas are wide apart. The well cannot be a large one. Still, it was a marked improvement in every way on the wells that had been previously drilled in the vicinity, and the high level of the gas-rock seemed a point of great importance.

In the well that is known as the Turkeyfoot well, three miles above South Toledo, the Trenton had also been found at a higher level than on either side previously, but it was lower by 113 feet than the Waterville well. The Turkeyfoot well was unproductive.

A second well drilled near Waterville tends to dampen these expectations of a new gas-field at this point, as it is reported unproductive.

Perrysburgh.

Several wells have been drilled within the last year at and near Perrysburg and in the interest of this town.

The first of them was cased at 402 feet in the Niagara shale, underneath which ninety feet of Clinton limestone were found. The Trenton was struck at 1,305 feet, or at about 700 feet below tide, and was unproductive. No improvement was effected by continuing it to 1,600 feet. A little shale-gas was found at 800 feet.

Sylvania.

At Sylvania, on the Michigan border, a section of unusual geological interest is found. Reference has been made to it in a preceding chapter, (pages 18, 19, etc.) A notable flexure of the surface strata is found here All of the facts at hand seem to point to this feature as an extension of the Findlay break. The Survey has called repeated attention to this broken structure, and has urged the desirability of testing this neighbor-

hood, so long as indiscriminate and random drilling is going forward on all sides. It has been urged that such structure could hardly be without effect in the concentration of oil and gas. Drilling has recently been undertaken here, and not by one company, as would have been prudent, but three or more wells are being sunk at the same time. The wells are not yet complete, but the records as furnished by the drillers are not only unexpected but unintelligible. One thing, however, is clear, viz., the promise held out by the Survey is not to be verified. Before this volume is completed it will be possible to present a summary of the facts that are now being gathered.

The two central southern townships of Wood county, Bloom and Henry, have been proved to be as valuable sources of gas and oil, respectively, as any other equal areas of the new field. Bloom township produces gas almost exclusively, and nearly all the wells of Henry township produce oil, but with the oil large quantities of gas are found, sufficient to make the wells flow in most instances. The oil production of Henry township is much more important than that of any other township in the entire field. It is here that the greatest wells yet found in the Trenton limestone are located. In fact, the latter belong in a list to which but very few oil fountains of any fields are admitted. The oil of the North Baltimore field ranks higher also in intrinsic value than that of any other part of the new production. Taken all in all these two townships constitute the most remarkable and most valuable section of the new horizon.

Bloom Township Gas-Field.

The district included within these limits is, beyond question, one of the most important divisions of the new field. In fact, it gives promise of becoming a more valuable source of gas than even Findlay itself, not only on account of its large acreage and its extremely productive wells, but also from the fact that it is already covered by the drilling companies in tracts of such area that its resources are not likely to be frittered away by drilling in advance of all possible use. Of this new field there are various centers. They are not united by any common bond of ownership and interest, and might well enough be counted entirely separate and distinct from each other. A common name is, however, desirable for this district, and none, on the whole, is more suitable than the name of the township which is the chief center of production thus far. The wells to be described under this division are located at the following villages and in the country adjacent to them:

Bloomdale, Bairdstown, North Baltimore, Jerry City, Welker, Cygnet and Trombley.

The field extends along the line of the Baltimore and Ohio Railway in an east and west direction in a belt of eleven miles, from North Baltimore on the west to Godsend Water-tanks on the east. Its northern and southern boundaries have not yet been defined. So far as the surface of this district is concerned, it is a slightly diversified plain about 750 feet above tide-water. North Baltimore is 739 feet; Welker is 736 feet; Bairdstown is 750 feet; Bloomdale, 755 feet; and the Water-tanks, 750 feet above tide. Geologically, it has been found to be a high-lying terrace of Trenton limestone. At the extremities of the section named, the Trenton lies 400 feet below tide, falling quite rapidly in both directions but most abruptly to the westward. These elevations are seen in the following figures: In well No. 1, North Baltimore, the Trenton is 451 feet below tide, which excludes this section from the gas-field; in the Peters well, North Baltimore, the limestone is 380 feet below tide; in the Bairdstown well, 315 feet; in the Simons well, 301 feet; in the Bloomdale well, 360 feet; and in the Godsend well, No. 1, 391 feet. Although the surface of the ground is flat, the underlying Trenton is seen to bend in a low arch, culminating in the Simons well. Within these high levels there are occasional hollows, or abrupt depressions, as appears from the facts in the Rocky Ford well, where the Trenton was found 113 feet lower than in the Simons well, although only a mile distant from it. A trough or sag of the strata extends accross the field, in a north-easterly direction. It was first disclosed by Winchell's geological map of 1871–2, in which the Waterlime was shown to be the surface rock throughout the valley of the main branches of the Portage river. This sag separates the Bowling Green island of Niagara limestone (gas territory) from the great area of this formation that makes the Hancock and Wood counties gas-field.

The structure of Bloom township gas-field is represented in the accompanying diagram (section from Deshler to Tiffin.)

North Baltimore.

Well No. 1, at North Baltimore, was drilled in the summer of 1886. An excellent and discriminating record was kept of the work by Mr. J. W. Elliott, one of the contractors, and was by him placed at the service of the Survey. No better or clearer record has been furnished from the entire field, and if the number of such could be increased, the progress of our knowledge would be much more rapid and certain. The record is as follows, substantially in the driller's words, and it must be borne in mind that the driller had no knowledge whatever of geological

terms or of the divisions to be expected, but was simply intent on getting from the first well drilled by himself in the new field a register that he could rely upon for future guidance. The section is represented in the plate that occupies page 112:

Soil and clay	43 feet.
Brown limestone	107 "
Gray limestone	140 "
White shale	13½ "
Sand	89 "
Gray slate	47 "
Red rock	45 "
Gray slate	416 "
Black slate	290 "
Trenton at	1,190½ "

This record scarcely needs interpretation. The "brown limestone" is clearly the Waterlime. The "gray limestone" is, by the same token, the Niagara, and the thirteen and one-half feet of "white shale" that follows is that persistent element, the Niagara shale. The eighty-nine feet of "sand", so-called, is the Clinton limestone, which, however, in its outcrops is often known by the name of "sandstone". The "gray slate" and "red rock" together constitute the Medina. The Hudson River and Utica shales are well distinguished in the two lowermost divisions. The Trenton was found at 1,190½ feet, or 451 feet below tide. Its behavior under the drill is instructive in this connection. At seventeen and one-half feet in the Trenton, oil was struck. At twenty-eight and one-half feet gas was found. Then came seventy-seven feet of barren rock, beneath which, at 1,295½ feet, salt-water came in, in quantity. The well was plugged and filled forty-four feet, and then shot with sixty quarts of nitroglycerine. It filled up rapidly after the torpedo. A week was used in cleaning, packing and piping, when it flowed twelve to fifteen barrels for a day or two. The flow was, however, soon arrested for the greater part, at least was reduced to two or three barrels per day, and it has at length given out altogether. The oil proved to be of the very best grade of oil from the new field. When fresh, it had a gravity of 41 B.; the oil from the tank showed a gravity of 39° B. The facts here detailed have interested oil producers very much, and territory has been leased on all sides on a large scale, with reference to future operations.

A second well, drilled on the Frank farm in the valley of the Portage, one-half mile south of well No. 1, reached gas, oil and salt-water under conditions that do not allow of their ready separation. Thus far the well is of no value. The Trenton lay at about the same depth as in well No. 1, viz., at 1,177 feet, or about 447 feet below tide. These two

wells are thus seen to be in the steep downward slope that has been already referred to, which lies west of the gas belt.

How abrupt the boundary is appears from the register of the next well, viz., the Peters well, which is situated about three-quarters of a mile east of well No. 1. The elevation of the well-head is 730 feet above tide. The Trenton was struck at 1,104½ feet, or 380 feet below tide. The record is as follows:

Drift	16 feet.
Waterlime and Niagara	215 "
Niagara shale	15 "
Clinton limestone, bearing a good vein of gas.	
Cased at	297 "
Medina shale, or red rock	60 "
Hudson River and Utica shales	758 "

The well proved to be a gas well of fair volume. The supply was obtained in the uppermost ten feet of the Trenton. Drilling was continued to 1,127 feet. No opportunity to obtain a satisfactory measure of the gas has yet been found; but a test applied on November 22, showed the outflow to be 2,300,000 cubic feet per day, while a considerable volume was escaping elsewhere at the same time. The well is producing nearly if not quite 3,000,000 cubic feet per day. It is to be utilized at once for domestic supply in North Baltimore.

Bairdstown.

The Hancock Oil and Gas Company put down a well at this point in the summer of 1886, reaching the Trenton on July 23d, at a depth of 1,065 feet, or 315 feet below tide-water. The record is appended:

Upper limestones about	250 feet.
Well cased at	276½ "
(Could have been safely cased 30 feet earlier.)	
Gas in quantity at	300 "
Red rock, 20 ft. thick, begins at	325 "

But a small volume of gas was reached in the cap of the Trenton. The rock proved hard, white, and glassy. At 1,099 feet, or thirty-four feet in the Trenton, the rock grew coarser and somewhat shaly. At 1,105 feet it became hard and close again. At 1,118 feet it grew more open, and at 1,123 feet, or fifty-eight feet in the Trenton, a vigorous flow of gas was released. The well has not been measured, but it is safe to estimate the daily production at several million cubic feet. Up to the present time, no use has been made of the gas, but the well has been sealed in for the last few weeks, and will presently be utilized in supplying heat and light to the town. The most noticeable feature on the

geological side is the depth at which the main gas vein was struck, viz., fifty-four feet in the Trenton. Other facts of the same character are also found in Findlay wells.

Since the preceding statements were made the well has been utilized.

The Simons Well.

At the date of its completion, the Simons well produced a larger volume of gas than had yet been measured from any well of the state, the famous Karg well not excepted. The gas was measured, however, through the casing which is $5\frac{5}{8}$ inches in diameter, while the Karg well was not measured until it had been tubed with 4-inch pipe. The Simons well, if confined to a 4-inch pipe, will be found to yield a little less gas than the Karg. It is thought to maintain its vigor undiminished, but no test has been applied since the original measurement. It is situated one and a half miles north and a little west of Bairdstown. It is nearer to this than any other railroad station. It is located on a farm standing in the name of A. Simons, in the northwest corner of Section 29, Bloom township. The farm is a lonely one, and is not only not located on any public road, but is not in sight of any road, and the nearest houses are nearly a mile distant from it. In much of the land of the farm, the underlying rock is so near the surface that it is laid bare whenever a forest tree is uprooted. Thirty or forty acres were here cut out of the original black swamp in a little block, and a small farm was set in order, upon which the cheapest possible equipment of necessary buildings was placed, a house on which $100 or $200 might have been expended, and a log barn that would not cost half as much in money outlay. Fields were fenced and an orchard was set. A narrow living was secured for a household by unremitting toil, and by the reduction of all demands to the bare necessities of life. A well sunk a few feet into the limestone rock furnished an abundant supply of water, rank with sulphuretted hydrogen, for farm and stock. Gas, bubbling up through the pools left by overturned trees, tainted the air and it was long ago found that a hollow corn-stalk or reed, thrust into the black mud at the bottom of these pools, would bring up gas enough to maintain a flame for some time. The owner seems to have had a presentiment that his little farm contained something out of the usual order, as he sought such advice in matters geological as his grade of intelligence led him to trust, viz., the location of mineral wealth as indicated by the witch-hazel branch and also by clairvoyant revelations. From one or both of these sources of information, he learned that his farm contained valuable deposits of silver ore, and also two veins of oil. Gas was not known at that time either to the geologist or the divining rod expert, and this accounts for its omission from these witch-hazel

treasures. Enriched by the consciousness of these unusual sources of wealth, and doubtless happier than if he had sought to develop them, he pursued the even tenor of his way, and died, leaving the little farm to his natural heirs. Findlay gas and oil were discovered in due time, and Northwestern Ohio was covered with leases for drilling privileges. The country around Bairdstown was taken up in considerable amount by the Hancock Oil and Gas Company. The Simons farm was included, with many others, in leased property; and when it became necessary to drill a well to hold these leases, it was found that this particular tract would cover as much territory as one drilled at any other point. There was, moreover, a well available that would furnish water for the boiler, and last, but not least, the surface indications of gas that have already been described were not without influence. The well was drilled by the lessees, with W. M. Martin in charge of the work. Drilling was begun in July, 1886, and on the 29th the Trenton was struck at a depth of 1,041 feet, or 301 feet below tide-water, thus making the well the shallowest of all that had been drilled up to that date in the new oil field. The upper limestone was 256 feet in thickness. The casing was set at that depth. The Medina, or red rock, came in at 300 feet, and had a thickness of fifty feet. A considerable flow of gas was found in descending, and notably at 700 feet in the Hudson River shales. The Trenton yielded gas the moment it was struck, but at nine feet in the rock a powerful flow was set free. The gas increased with every bit. The Trenton as seen from the fragments thrown out from the casing was highly crystalline and porous, more so than in any other well observed, except the Karg. Measured on the 31st, the flow of gas was 4,000,000 cubic feet per day. This made it second in the list of northern Ohio wells. On Tuesday, August 3, the well was drilled eight feet deeper, and the flow was trebled in volume. The tools refused to descend deeper, dancing in the well like rubber balls. On Saturday, August 7, the flow was again measured. The column of gas showed four pounds open pressure in the casing, and this pressure indicates a production of 12,421,968 cubic feet per day. This is the largest volume of gas that had been thus far measured from any Ohio well, but as has been already stated, if the Karg well had been measured through the casing, it would have exceeded this amount by one or two million feet. The sight of the immense column of flame rising from the burning well above the tree-tops of the primeval forests and illuminating the sky for miles on all sides, and the noise of the escaping gas, like the roar of a cyclone or a great cataract, conspired to impress upon the minds of the beholders more forcibly than anything else could do the significance of the wonderful discovery that was made when Findlay gas was brought

to light. A six-inch hole 1,000 feet deep in this out of the way corner suddenly becomes worth many times over the value of the little farm in which it is located. To duplicate the power that was surging out from this small opening every day, it would require acres of the original forest, for the growth of which centuries had been used. The well soon passed into the hands of the Northwestern Ohio Gas Company, and has been utilized in its extensive system of gas transportation.

The Rocky Ford Well.

A mile northwest of the Simons well a well was drilled at the same time and by the same company, viz., the Hancock Oil and Gas Company, the fortune of which was very different from that last described. The well was located on Section 29, Bloom township, at the Rocky Ford of the Portage. The record of the well is unusual and is full of interest. The elevation of the casing is about 730 feet above tide. But six feet of drive pipe were required to reach the rock. The limestone seen in the bed of the river at the Ford is the Waterlime, and it is dipping westward at the rate of two or three degrees. The results recorded are as follows:

Drift	61 feet.
Blue limestone	200 "
Gray limestone	169 "
Casing at	375 "

The Niagara shale, Clinton and Medina all appear in due order, the last being fifty feet of red rock. The Clinton proved petroliferous, and several barrels of oil were bailed out at 325 feet. Salt-water also came in at the same horizon. The descent of the limestone from the Simons well was marked, and a calculation as to the depth at which the Trenton would be found was based upon it. The figure taken was 1,160 feet, but no allowance was made for the lower level of the well-head. The Trenton was afterward found at 1,154 feet, and the difference between this figure and the calculated one would be explained by the difference of elevation in the well-heads. The Trenton is here 424 feet below tide. The drilling proceeded regularly after the Clinton was passed to 875 feet, where a short-grained shale was struck that made great trouble in caving. It was called by the drillers "mud-rock," but was a common phase of the Utica shale, struck apparently at a bad angle, and thus disposed to fall. Gas and oil in small quantity were also found in a quite persistent horizon in the Hudson River shale, the one, viz., found at 750 feet.

When the Trenton was reached, it was found charged with salt-water, and the well was abandoned as without value. The sudden dip

of the formations in this interval is obviously connected with the great accumulation of gas in the Simons well. The Karg well, it will be remembered, stands in similar relations to the sudden descent of the Clinton limestone from the east Findlay terrace. This well is scarcely to be counted on the border of 500 feet rock. That border lies a few miles to the westward, unless the margin is more tortuous than we have thus far believed. The Trenton will be found to rise out of this swamp to the northward, and may give strong gas-wells on that side of the rise.

Jerry City.

A well was drilled in the summer of 1886 at this point, and reached the limestone at a depth of 1,155 feet, showing a continuation of the swamp described in the last record. The well was of no value.

A second well drilled in this vicinity gives a peculiar record. The Clinton limestone is found to be a true oil-rock, supporting a flowing oil-well with a daily production of 30 or 40 barrels for several months. The oil is lighter than most of the Trenton limestone oil, and is comparatively free from odor. It will be remembered that the Rocky Ford well, described on a preceding page, yielded oil from the Clinton horizon. These facts have awakened some interest as to a possible oil-field in this horizon, and in this vicinity. In answer to questions touching this point, it can be stated that the horizon has proved productive in an important sense in but one out of hundreds of wells that have penetrated it, and that therefore no great expectations are warranted in regard to it.

The well named above is located on the Weyrick farm.

Bloomdale.

One of the first wells to be drilled in the prolific gas-belt now under consideration was sunk at Bloomdale by the Hancock Oil and Gas Company, with Mr. W. H. Gilbert in charge of the work. The well was brought in during the month of May, 1886. The record is appended:

Drift	16 feet.
Upper limestones, gray, white and blue, including the Niagara shale, in which the casing was set	274 "
Red rock	30 "
Blue and black shales	715 "
Trenton at	1,065 "
Or 310 feet below tide.	
Well finished at	1,115 "

A fine vein of gas was struck, and an attempt was made to measure its flow on June 16, but at that time it was impossible to get access to the well except through small openings at a considerable distance from the casing, and the results are vitiated thereby. The figures obtained

range from 3,240,000 to 2,640,000 cubic feet per day. The flow at the open casing would, doubtless, have been more, probably not less than three and a half to four millions cubic feet per day. The well was quite promptly shut in and utilized in the heating and lighting of the village. The pressure rose to 100 pounds in 41 seconds, when the well was closed at the date mentioned above.

The Water-Tank Wells.

Four wells have been drilled up to the present time by the Northwestern Ohio Gas Company, in the interest of securing a supply of gas for Fostoria. All are located on territory leased for this purpose near the Godsend water-tanks of the Baltimore and Ohio Railway, four miles west of Fostoria. All are located in Cass township, Hancock county, and within the limits of the Kelly farm. They are known by the company as the Kelly wells, Nos. 1, 2, 3 and 4. The first one was brought in on August 7, 1886. The Trenton was struck at 1,136 feet. The elevation of the surface is, approximately, 745 feet, and the Trenton is thus seen to be about 390 feet below tide. A fair but not a great flow of gas was found at this point in the surface of the Trenton. Greatly increased vigor was secured from the well by deeper drilling. A measurement of the gas, as executed by Mr. J. Gwynn, of the Fostoria gas-works, made the flow 3,187,000 cubic feet per day. The first gas was found at 1,138 feet, or three feet in the rock. A thin bed of shale occurred between 1,138 feet and 1,145 feet, and another bed between 1,145 and 1,149 feet. At 1,145 feet the gas flow received its final increment. The well was finished at 1,160 feet. The fourth well, which was drilled in November, 1886, is much more vigorous than the first three. It is counted as equal to two of those that preceded it. To explain this sudden increase, it is only necessary to say that the Trenton lies 12 or 15 feet higher here than in the other wells.

This completes the list of wells drilled in the Bloom township gas-field up to Dec., 1886. The development of a territory of great value and of greater promise has been fairly entered upon; and the resources are certain to be of immense importance to the thriving towns of northwestern Ohio. The new fuel gives to these towns advantages far greater, for the present at least, than the discovery of the best coal seams of the state within their immediate boundaries would do.

The statements made above show the situation of this part of the field in 1886. Great progress has been made during 1887 in the development of the gas territory of Bloom township. Two strong corporations, viz., the Northwestern Ohio and the Toledo Natural Gas Com-

panies, have obtained control of almost all the portions of the township that are counted promising in this respect. More than a score of wells have been already drilled and an enormous production has been secured. In fact, Bloom township is the main center of distribution of natural gas to all of the surrounding country. Two pipe lines extend from it to Toledo, and it is substantially the same field that furnishes gas to the Fremont and Fostoria lines.

None of the later wells have reached the large proportions of the Karg well of Allen township or of the Levi Simons' well already described, but several of them have a daily flow exceeding five million cubic feet, and not one of them sinks as low as one million feet per day. Measurements have not been secured by the Survey of many of these new wells, but the following are believed to be the most important, viz., the Niebel, the Brandeberry, the Abram Baker and the Gray wells. In addition to these, excellent wells have been obtained on the following farms, viz., the Fife (four wells), Moke, Stove, Weisel, Rhoads, E. Simon, Minks, Handwerk, Myers, J. C. Baker and the Byal farms. The Weisel well, as reported by C. C. Conroy, showed six pounds pressure in a 3-inch pipe, which stands for a production of 3,800,000 cubic feet per day.

The gas territory as now defined occupies the following sections in whole or in part, viz., sections 19, 20, 21, 22, 23, 27, 28, 29, 30, 31, 32, 33, 34, 35 and 36. It is quite possible that it may be found necessary to add a few sections to this list, and it is also to be noted that one or two sections are included here that have not yet been proved to be productive. The latter are, however, surrounded by productive territory.

A few sections of Perry township to the eastward may also prove to be gas-bearing on a fair scale.

The territory as now laid down agrees quite closely with the areas of Niagara limestone, as represented on Winchell's map of 1871–2, as already pointed out. Its northern limit is found in the Portage sag, referred to in several other connections. To the southward the gas territory of Bloom township unites and is continuous with the Allen and Cass townships field already described.

On the west the boundary is sharp, being effected by the northward extension of the Findlay monocline. The breadth of a single farm, and sometimes of a single field, is often enough to cover the change from gas to oil production.

It is probable, from recent investigations, that the eastern boundary does not extend far beyond the territory already proved.

Several millions of dollars have been already invested in the exploitation of the Bloom township gas-field, with the surest prospects of being returned to the investors, with large additions.

Pipe Lines.

The Northwestern Ohio Company's line extends from the southern boundary of sections 10 and 11, Cass township, Hancock county, due north through Bloom, Portage, Center and Webster townships, of Wood county, and thence to Toledo, a distance of thirty-three miles. The entire line is laid with 10-inch pipe. This company counts at the present time twenty-four producing wells, and among these, as already stated, are many of the largest wells of the entire field.

The Toledo Natural Gas Company has a line about thirty miles long, extending from the Hancock county line at its contact with Sections 31 and 32, Bloom township, in a due north direction. It is three miles west of the line previously described. For most of the distance 10-inch pipe is used, but a few miles nearest Toledo are laid with 12-inch pipe. This company has a number of fair wells in the territory already reviewed, embracing several of those previously named.

The Fostoria and Fremont lines consist of 6-inch pipe.

The Tiffin line consists of two and one-half miles of 6-inch pipe and nineteen miles of 8-inch. This last-named company has thus far depended almost entirely on the famous Thorntree well, of Marion township, Hancock county, but in August, 1887, a well was finished for the line that exceeds, according to the report of Superintendent Brooks, all the wells of the new field. Its open pressure in the casing was found to range between six and seven pounds, thus showing a production of more than 15,000,000 cubic feet per day.

The well is located on the farm of Adam Roth, section 14, Marion township, near the center of the section, about a mile south, and a little east of the Thorntree well.

The Henry Township Oil-Field.

The oil production immediately to the west of the Findlay break as the latter extends through Henry township, far exceeds in importance that of any other equal area in the new field. The productive territory is limited to the two easternmost lines of sections of the township, viz., sections 1, 2, 11, 12, 13, 14, 23, 24, 25, 26, 35 and 36. These sections are by no means of equal value in this regard, but the third, fourth, fifth and sixth of the square miles named above bid fair to take rank with the most famous centers of production yet found in the United States. Section 14 must be added to this list, but only a small portion of its eastern side is likely to be found good territory.

More than fifty wells have been drilled within the areas above noted during the last year, all of which have produced oil in valuable amount,

and some of which stand easily at the head of the oil production of the state.

The development of the field began with the drilling in of a well on the David Fulton farm, Section 14, about the first of December, 1886. The well was known at the time as the Hammansburg well. Its record, as kindly furnished by C. C. Conroy, Esq., is appended:

Upper limestones (Waterlime and Niagara)	300 feet.
Slate (Niagara shale)	30 "
Second limestone, (Clinton)	70 "
Cased at 400 feet.	
Trenton limestone reached at	1,160 "
(430 feet below tide—approximate).	

Oil found at 1,192 to 1,194 feet. Filled a 250-barrel tank in twelve hours.

This was the largest production that had been found outside of the Lima field, no well in the Findlay district having thus far yielded more than half this amount per day. The consequence was that there was a great influx of drillers into the immediate neighborhood, and the new territory was eagerly competed for.

The second well to be brought in is known as the Henning well. It is situated about 500 feet eastward from well No. 1. It was completed on February 25th, 1887. The Trenton limestone was reached at a depth of 1,206 feet, and the oil at thirty to thirty-seven feet in the limestone. At a depth of thirty-three feet, 250 feet of oil appeared in the well. Below the first oil streak a hard crust occurred. When this was penetrated the drill seemed at first to fall as if it had reached a cavity. Presently the force of the gas that accompanied the oil became so great that the weight of the tools was borne up, and the walking beam thus relieved, played rapidly up and down. The oil filled a 250-barrel tank in fifty-seven minutes, and the total production of the first day ranged between 1,500 and 2,000 barrels, according to judicious estimates.

Facts like these put a new face on the oil production of northwestern Ohio, both as regards producers and purchasers. In spite of the low and the steadily shrinking prices for the oil, production could be maintained on wells like the last. The possibilities of the new territory as revealed by the Henning well led to an immediate reduction in the price paid for oil throughout the fields. The Henning well is now producing sixty to seventy barrels per day.

After this surprising record, the development of the field was pushed forward rapidly until in July a well was brought in that belongs to a class to which very few in any part of the world are admitted. The Slaughterbeck well, No. 3, in the southwest quarter of section 13, the first day after the oil-rock was reached, and without

any aid from torpedoes, put 4,800 barrels into the tanks and then overflowed upon the ground for two hours. It is entirely within limits to say that its first day's yield was in excess of 5,000 barrels. At the end of two months it was still producing between 2,000 and 3,000 barrels per day when allowed to flow. Its total production to October 1st, 1887, will fall little, if any, short of 100,000 barrels. This well marks the highest point reached by the new oil-rock, and would ensure it a place, if any doubt existed as to its character, among the great oil reservoirs of the world. In this region the Trenton limestone is found at a depth of about 1,150 feet, or about 440 feet below tide. It lies very nearly level throughout this region.

Another great well has recently been brought in (September, 1887,) on the Jere. Foltz farm, section 12, near the line of the T., C. & S. R'y. This well was shot, and in the first two and one-fourth hours thereafter put 1,000 barrels into the tank.

It is not necessary to follow the details of the development further. The producers of the Henry township field could safely sink wells even when the price of oil was reduced to fifteen cents a barrel, and it required varied arguments, the most potent of which was the intimation that tankage would not be provided for the oil, to induce them to entirely suspend the work of the drill through the latter half of 1887, except as the requirements of contracts might occasionally demand.

The practical men who are familiar with the history now briefly sketched entertain great expectations of this portion of the field. The most conservative among them declare that with a price of thirty cents per barrel for oil, the production of Henry township would in sixty days rise to 50,000 barrels per day. There are those who believe that these figures could easily be doubled within this single township.

The cost of drilling is comparatively light. Casing does not exceed 400 feet, and the wells are but little more than 1,200 feet deep.

Thus far but few of the wells have been "shot". So long as the production exceeds 100 barrels per day, they are let alone. Torpedoing restores their production for a time. No pumping has yet been done here.

The character of the oil has already been noticed in the description of the first well at North Baltimore. When fresh, it has a gravity of fully 42° B. In other words, it is livelier and more valuable for refining than Lima or Findlay oil. A more extended discussion of the character and real value of the various grades of Trenton limestone oil will be reserved for a separate chapter.

The field is quite limited in extent, as already implied. It consists of a belt, of less than two sections (or miles) in breadth, and extending

five or six miles in a north and south line, on the east side of which great accumulations of gas are found, while on the west the drill strikes salt-water as soon as the oil level is reached. In some parts of the field, salt-water is found with the oil-sand; in all parts it comes in as the wells begin to fail. The value of the field is no doubt enhanced by the near presence of the Portage sag, a northeasterly depression in the strata, which makes the northern boundary of the field as now defined. Wells drilled in this territory strike salt-water promptly.

Wells of Van Wert County.

The drilling done to the west and north of Lima will next be described. The experience of Van Wert and Delphos in their search for the new source of power will be given at this point. The Citizens' Natural Oil and Gas Company was organized early in 1886 in the former town, with a capital stock of $3,000 in $10 shares. The contract to drill a well was let to the Lima Drilling Company. Work was begun near the center of the town on April 23d, and on May 15th the Trenton was reached at a depth of 1,220 feet, or 434 feet below tide. For the record of the well and for access to an excellent set of samples of drillings from different depths, the Survey is indebted to Dr. D. L. Corbin, of Van Wert. The record is herewith given, the divisions being established on the samples examined:

Drift	32 feet.
Waterlime, blue and hard	148 "
Niagara limestone	185 "
Niagara shale	15 "
Clinton limestone	40 "
Well cased at this point.	
No red-rock noted.	
Medina and Hudson River shales, blue	510 feet.
Utica shale, dark	290 "
Trenton at	1,220 "
Gas in small amount, at	1,233 "
Hard shell	1,238 "
Oil	1,240 "

The well was shot from 1,230 to 1,242 feet, and the oil was thrown high above the casing. The pump was introduced, and it delivered oil in connection with salt-water in large proportion for a few hours. Then followed a small quantity of oil alone, fifteen to twenty barrels being pumped in all. The stream grew finer, and finally ran down to nothing. The gas was piped to the mills near by, and was used under the boiler for fuel, but the flow is insignificant, being less than 3,000 cubic feet per day. Here again, the presence of oil in quantities sufficient to be pumped attracted the attention, and inspired the confidence of prospec-

tors and drillers to such an extent that considerable territory has been leased for drilling privileges in this vicinity. The further tests that have been made up to the present time do not require minute description.

So far as results are concerned, the first record substantially covers all the subsequent trials. The level of the oil-rock is not altogether unfavorable to production, and its chemical composition is such as to give it a fair degree of porosity, but from some cause the conditions for large accumulations are wanting. Just enough oil has thus far been found to awaken the unnecessary fear among the people that valuable opportunities will be lost unless more drilling is undertaken.

Delphos also drilled in the spring of 1886. For the facts pertaining to this well, the Survey is indebted to Emerson Priddy, Esq., of Delphos. The well was begun at an elevation of 775 feet above tide, and the Trenton was struck at 1,228 feet, or 453 feet below tide. The record is appended, the divisions being established on the excellent set of drillings from various depths preserved by Mr. Priddy:

Drift	5 feet.
Waterlime and Niagara	340 "
Niagara shale struck at	345 "
Clinton limestone ending at	425 "
Red-rock, Medina shale, at	430 "
Well cased at this point.	
Hudson River shale	568 feet.
Utica shale	200 "
Trenton at	1,228 "

The structure of the Trenton limestone as found in this well, is as follows: Uppermost two feet, hard; then oil and salt-water in small amount; hard shell, one foot; fine and close, one foot; shell, one foot; fine and hard, seven feet, at which point salt-water was found in large quantity. The well was plugged at 1,250 feet, and then shot with forty quarts of nitro-glycerine below 1,228 feet, but without any favorable effect. The largest quantity of oil obtained was from a Hudson River horizon, at 750 feet, but even this was of no value whatever. The presence of red-rock in this well is of special interest, as this mark of the Medina has not been noted in the Allen County wells.

Wells of Putnam County.

Putnam county could not fail to feel the excitement in regard to oil and gas that was sweeping through all the territory to the south and east of it. Ottawa, Columbus Grove, Leipsic and Kalida have each tested the Trenton rock within the last year, and although they have secured no valuable returns to themselves, the facts developed are of great value

in the general discussion of the new oil horizon in northwestern Ohio. These towns drilled their wells in the order named above.

Ottawa.

In the drilling that has been done in Putnam county, a woman led the way. Mrs. Beckmann had a well drilled to the Trenton limestone, at her own expense, on her property in Ottawa, in the winter of 1885. The record is as follows:

Drift	95 feet.
Niagara limestone	497 "
Shale	718 "
Trenton limestone struck at	1,330 feet.
Or 602 feet below tide.	
Gas found at	1,345 "
Oil at	1,352 "
Well finished at	1,365 "

After torpedoing, fifteen to twenty barrels of oil of a heavy grade were pumped. A sample of the oil tested, after considerable exposure, was found to stand at 33½ B. The pump soon ceased to deliver oil, and salt-water was its only production. The well was forthwith abandoned. The fact that oil was found in the well, however, was interpreted as certainly favorable to the promise of the district, and a second well was soon under way, drilled by a number of prominent citizens organized under the title of the Ottawa Natural Gas Company. This well is located a half mile or more east of well No. 1. Its record, as furnished by Mr. S. F. DeFord, superintendent of schools in Ottawa, is as follows: The identifications of the strata were made on the basis of drillings saved by Mr. DeFord.:

Drift	50 feet.
Waterlime	220 "
Niagara limestone	260 "
Niagara shale	15 "
Clinton	35 "
Medina and Hudson River shales	434 "
Utica	300 "
Trenton struck at	1,314 "
Or 586 feet below tide.	

The Trenton was close-grained and hard, but between nine and twelve feet from its upper surface a small vein of gas was struck, and a little oil was also found a few feet lower. The well was shot, and a small increase in the flow of the gas was obtained, but the flow had no force. An anemometer measure taken soon after the well was completed showed it to be producing 1,270 feet per day.

Columbus Grove.

This enterprising village also entered the field of exploration at an early date. A company was organized of leading citizens, and a trial well was drilled adjoining the railway station in December, 1885. The record is not very complete, but the essential facts are given below:

The drift was 17 feet thick, the upper limestone 470 feet, and the Trenton was found at 1,278 feet, or 526 feet below tide. Gas was found at 740 feet in the Hudson River horizon, and a small stock of oil was found in the Trenton. A pump was set to work, and six barrels of oil were delivered by it, and this was the end. The oil was of 34° gravity.

Leipsic.

A company which was organized in this village in January, 1886, under the title of the Leipsic Natural Gas and Oil Company, proceeded forthwith to drill a well. The well was completed on April 3d. The record is somewhat incomplete, but the following facts are furnished by Dr. J. C. McClung, President of the Company, and Mr. J. A. Carrothers, contractor:

Drift, mainly blue clay	78 feet.
Upper limestone, about	600 "
Well cased at	684 "
Trenton struck either at 1,447½, or at	1,456½ "

Its surface is, therefore, about 700 feet below tide. Gas was found at a depth of ten feet or more in the Trenton, and oil a few feet below. At the same level with the oil a great volume of salt-water was unlocked. It filled the well and made several overflows. The entire column was taken, at first, to be oil. A tank was erected and pumping begun. A few inches of oil were accumulated in the tank, but the pump found nothing further to work upon. The gas production was insignificant in amount.

Wells have also been drilled at one or two other points in the county, but thus far no valuable production can be referred to them. If Putnam county contains gas or oil in large and remunerative amount, it remains yet to be discovered, and with the chances apparently against said discovery.

The full record of another well drilled here in September, 1887, is not at hand, but the statements made in regard to it imply considerable more promise in the oil-rock. If any valuable production is found here, it will be a decided exception to the law of the 500 feet limit of production. Such exceptions are thus far very few.

Kalida.

Kalida organized a company to test the Trenton in its vicinity in the summer of 1886. In the rocks that are exposed near the town there are several flexures that have always attracted the attention of those observant of such facts. Well-marked anticlinals, though on a very small scale, are found in the valley of the Ottawa River, two miles above Kalida. The well was not located, however, near this point, but a half-mile north of the town instead. The record, which was kept by Judge George Skinner, to whose intelligent interest in all questions of this sort the county is greatly indebted, is as follows:

Estimated elevation of well-head	725 feet.
Drift	15 "
Limestone	585 "
Shale	701 "
Trenton struck at	1,301 "

Or 576 feet below tide.

At 70 feet, red sand was reported; at 355 feet, light-colored limestone; at 500 feet, a clay seam, which is, undoubtedly, the Niagara shale. A small vein of gas was found at 1,308½ feet, and a little oil at 1,316 feet. The rock was soft from 1,345 to 1,364½ feet, where salt-water was struck in quantity, and the drilling was arrested. The well is of no value.

The Northwestern Counties.

The attempts of the four northwestern counties of the state, Fulton, Williams, Defiance and Henry, to obtain gas or oil from the Trenton limestone, remain to be described in completing the account of this portion of the state. Drilling has been disastrous to most of the contractors who have undertaken these wells, chiefly from a lack of knowledge of the geological section that was to be expected here. The Ohio shale enters these counties, and is found in five out of six wells in which drilling has been begun. This fact ensured the presence of the entire limestone column of the state, instead of a half of it, or less, as is found in all of the wells of the main fields. Water, and salt-water at that, is also certain to be struck in this great series of Devonian and Upper Silurian limestones, so that there would be required from two to six times as much casing for the wells as is needed in Wood, Hancock and Allen counties. In addition to this, the drift-beds are excessive in many places; and some of them are filled with water, giving rise to quicksands of a most troublesome character for the driller.

These counties, so far as they are covered with Ohio shale, all abound

in surface indications of gas derived mainly from this shale. The gas is sometimes found in the shale itself, where it originates, but often in the beds of drift overlying the shale. In the latter case it may be derived in part, also, from vegetable matter in the shape of timber, soils, etc., that are imbedded in the drift deposits. Throughout this district the water supply of the drift is somewhat defective, and deep wells are required wherever a permanent supply of well-water is to be obtained. The driving or drilling of these deep wells has released, in many cases, considerable quantities of this natural gas, some of which has been utilized, for a number of years, for heating purposes in private residences. Already familiar, in a small way, with the presence and the use of natural gas, it was no wonder that these towns set out with a good deal of enthusiasm in quest of the new horizon. The most was made of these surface indications, and many people felt entirely confident that to obtain a full supply, it was but to ask and to receive. The experience of the last six months has, however, changed all this. Of the six wells started early in 1886 within these four counties, two reached the goal toward which they were directed, by the end of that year, but only to find the Trenton rock either altogether dry or buried in a flood of salt-water. The remaining wells struggled along with difficulties altogether unexpected in the outset, and one of them gave over the discouraging undertaking when only half-way down.

Delta.

This thriving village of Fulton county had long made use of natural gas on a very limited scale. The water wells of the vicinity are 100 or more feet in depth, and some of them have brought up small but persistent supplies of gas, and this has been used in at least one instance in the village for heating purposes, viz., at the residence of Mr. Barber. The supply was derived from the drift, it is true, but the ultimate source of it was, no doubt, the underlying shale None of this gas came from the deep source that Findlay has struck. So far as this latter horizon is concerned, the numerous small gas-wells of the northwestern counties have absolutely no significance. The gas not only comes from a different source, but it has a different composition from the Trenton supply.

Delta began to drill in November, 1885, and abandoned the work in April, 1886. The record is a very instructive one so far as it goes, but it is profitable for instruction only. Mr. J. E. Brownyar was the contractor. He undertook the work with the expectation of finding a section similar to those of Findlay, Bowling Green and Toledo. The record, as kept by him, is as follows:

Drift	Clay	93 feet.	
	Quicksand	5 "	
	Gravel	17 "	115 feet.
Ohio Shale	Black shale	50 feet.	
	Light shale	15 "	
	Black shale	68 "	
	Limestone boulders	45 "	
	White soapstone	14 "	
	Hard rock	1 "	
	White slate	10 "	203 feet.
	Limestone, white	712 "	
	" sandy	92 "	
	" shaly	238 "	
	"	90 "	1,132 feet.
Red rock at			1,450 feet.

Where the well, at present, terminates.

No samples were saved by which the record could be divided or distributed or corrected. There are several anomalous features in the record, as it now stands, that would undoubtedly disappear, if a careful inspection of the drillings had been made possible. Reduced to its briefest terms, it is as follows:

Drift	115 feet.
Shale	203 "
Limestone series	1,132 "
Medina shale at	1,450 "

The Trenton is due at about 2,150 feet. The well required to be cased to the very bottom of the present drilling in order to comply with the terms of the contract. All thought of getting any valuable returns from the well had disappeared in the long struggle with solid limestone and salt-water. The geological divisions that seem probable are as follows:

Upper Helderberg limestone	50 feet.
Lower " "	650 "
Niagara limestone and shale	330 "
Clinton limestone	90 "

It is possible that all of these figures are somewhat in excess of the facts.

The Ohio shale is seen to have a similar composition to that which is found to the eastward. The divisions here seen prove fairly constant in northwestern Ohio, as will be shown in later records. Drilling from this point downward to the Trenton would undoubtedly be a much easier matter than the descent to the Medina shale. With good fortune, the drillers would find the Trenton with six days' work after the tools were again started. The owners of the well may choose to settle definitely the question as to the character of the Trenton rock beneath them, after having already expended so much in their unavailing search. A little gas was found at 400 feet, or about eighty feet below

the surface of the great limestone section; but taken as a whole, the show of gas and oil was unusually light for a drilling of this depth.

Wauseon.

Drilling was begun at Wauseon in the spring of 1886. It was completed without valuable result in the early part of 1887. An unusual depth for the Trenton limestone was found here, viz., 2,135 feet, or 1,367 feet below tide. This sag was entirely unexpected, and up to this time no corresponding facts have been reported. The strata are seen to be pitching sharply down under the Michigan coal basin.

An excellent record was kept of this well in the shape of samples of the drillings from various depths by M. Britton, Esq., the contractor. The leading facts are as follows:

Drift			156 feet.
Ohio shale	Black	94 feet.	
	Soft, calcareous, blue	30 "	
	Black	70 "	194 feet.
Hard limestone with chert		20 feet.	
Soft clay shale		15 "	
Hard dark limestone		4 "	39 feet.
White shale			
Devonian and upper Silurian limestones (approximate)			1,100 feet.
Shales, Medina, Hudson River, Utica (approximate)			645 "

The Trenton was struck in January, 1887, at a depth of 2,135 feet. The first five feet were intermixed with slate. Gas was found at 2,152 feet, and oil at 2,158 feet. The well was heavily shot and the flow of gas and oil was considerably increased thereby. The gas reached a pressure of 100 pounds in twenty-five minutes, and is, in quantity, enough for three or four boilers. The pump has yielded, thus far, twenty-five barrels of oil.

Though the well furnished the ordinary small and deceptive display of gas and oil that belongs to this corner of the state, it was soon seen that it must be counted a failure, but the apparent success of Bryan, presently to be described, led to kindling the fires again, and sending the drill still deeper. No good resulted from the repeated trial, and the field, so far as one well record can determine such a fact, is valueless as a source of gas and oil.

The facts that appear here indeed, are peculiarly discouraging, inasmuch as a sag of the limestone is revealed in this territory that would be sure to be a salt-water basin if the Trenton limestone in it is of a porous character.

One unusual fact is to be noted in the Wauseon record. At 714 feet below the surface in the middle portion of the Waterlime series, seven

feet of a bituminous mineral that is indistinguishable from some varieties of coal, was reported by the driller. Samples were also furnished by Mr. Britton, who was present at the well when the mineral was reached and while it was being drilled through and pumped out.

The first conclusion on an inspection of the drillings would be that coal had been purposely or accidently thrown into the well and drilled into powder here; but Mr. Britton's positive and circumstantial testimony excludes such an explanation and renders it certain that the asphaltic matter of the Waterlime is at this point so abundant as to make a chief element in six or eight feet of rock. The constitution of the "coal" is as follows: (*Lord.*)

Water	1.80
Volatile combustible matter	20.65
Fixed carbon	66.35
Ash	11.20

It is not certain that this analysis represents the entire stratum.

Gypsum was also found in the Waterlime in notable quantity, as in most other complete sections of this great sheet.

Bryan.

Drilling was begun in Bryan in June, 1885, and the Trenton limestone was reached in November. The record was kept with care by Mr. David A Wolff, by whom it has been kindly furnished to the Survey. It is herewith appended:

Drift		154 feet.
Black shale	83 feet.	157 feet.
White slate	13 "	
Black slate	61 "	
Upper limestone		1,009 feet.
Shales		665 "
Trenton found at		1,990 "

Or 1,240 feet below tide-water.

A good deal of trouble was experienced in getting through the drift. There were eighty feet of quicksand that it was hard to pierce. Under the white slate, at 250 feet, quite a vigorous flow of gas was found. The Medina shale, red in color, was struck at 1,320 feet, and held for the length of a single screw. The well was cased at 1,345 feet. The Trenton had the usual characteristic odor of petroleum, but there was no notable flow of either gas or oil from it. The rock was hard and drilled slowly. The Bryan Company is to be congratulated, if for nothing else, on having finished the work undertaken. It is the second one to reach the

goal out of six wells that started in the summer of 1886 in this long and expensive search.

The statements above given show the situation at Bryan at the close of 1886. Its experience in the search for gas and oil which was resumed in 1887, makes a long and interesting supplement to the original history.

Drilling was continued in the first well for seventeen feet below the surface of the Trenton limestone, where the tools became fast. A new contractor was set to work in February, who proceeded to cautiously drill around the lost tools. This he succeeded in doing by the 16th of the month, at which date a greater depth in the limestone by fifteen feet was reached than in the original work. At this point a vigorous vein of gas, with which oil was associated in considerable quantity, was released. The column of oil and gas was thrown above the derrick, and in default of tanks the oil was gathered in pools around the well. During the first day the well produced more than 100 barrels of oil, in the judgment of the experienced operator in charge, and the flow of gas could not have been less than several hundred thousand feet per day.

These facts naturally produced great excitement throughout the community. They underwent the usual exaggeration as they were reported by telegraph and in the newspapers. The spray of the oil was carried by the wind for twenty or thirty miles into the country, and its penetrating odor was the first announcement to half the country that Bryan had "struck oil."

The news called together the leading oil producers of the Findlay and Lima fields, but by the time they had reached the town the well had lost much of its force and promise. On the fourth day after it was struck the flow of oil was not thought to exceed thirty barrels. On the sixth day it had fallen to ten barrels, and in a little more than a week the production had virtually ceased. The flow of gas continued in some force for a few days longer, but it also grew gradually weaker, and finally disappeared. After an interval the well was shot with nine quarts of nitro-glycerine, the object being to loosen the tools. The shot was not successful to the extent of allowing the tools to be recovered, and the well was at last abandoned after nearly or quite $5,000 had been spent upon it.

The facts above given were counted by the people of the town and by some oil producers as well, encouraging as to the pressence of oil and gas in paying quantities in this region, and two other wells were at once projected.

Well No. 2 was located 2,000 feet southwest of No. 1, and No. 3 one mile south of No. 1.

The records of the drillers are as follows:

	No. 2.	No. 3.
Drift	146 feet.	176 feet.
Black slate	114 "	88 "
Limestone	1,080 "	1,040 "
Shales	648 "	635 "
	1,988 "	1,939 "
Trenton limestone	47 "	35 "
Depth of well	2,035 "	1,974 "

Both wells were completed at about the same time, viz., in the first half of July. The first began to get oil, with considerable gas, at twenty-five feet in the Trenton. At forty-seven feet drilling was suspended for the reason that salt-water was struck at this point. The well filled up 1,500 feet with oil, as was believed. It was then shot with sixty quarts fo nitro-glycerine, by which the gas was temporarily increased. The pump was set to work, and its greatest production was twenty barrels on July 20th. By the next day only half of this amount could be raised, and well No. 2 was necessarily abandoned.

Well No. 3 began with much better promise than either of the wells previously described. It produced dry gas, the pressure of which, when closed, rose fifty pounds in eight minutes. The highest pressure recorded was 155 pounds, but it may be that time enough was not allowed to the well to attain its maximum. Trenton limestone gas found at this depth ought to have a very high ultimate pressure. In the course of a few days the volume was found to be sensibly reduced, and when the well was examined, 150 feet of water was found in it. This was thought to have come in from defective casing. The water was bailed out and the drill set to work to deepen the hole. The descent was arrested three feet below the point of beginning and an increased flow of gas was for the time secured. It is probable that at a little greater depth oil would have been found. Prudence required the work to stop where it did.

The latest fortunes of the well have not been ascertained, but the history given above leaves little room for doubt or uncertainty as to the result.

It will be observed that the last-named well found the gas-rock at a slightly greater elevation than either of its predecessors, the surface of the ground being counted of the same elevation throughout the district that includes the wells. This small excess in the level of the oil-rock was found, as it has so often before been found, connected with the

presence of dry gas in fair volume for a little time. Bryan itself occupies a slight roll or dome of the limestone, as can be seen by comparing the elevations of the Trenton in its wells and in the Wauseon well. Where the character of the rock is such as to make it a reservoir of gas, oil or salt-water, all such relief in its surface is sure to be effective in the way of petroliferous accumulations. The structure of the Bryan rock is highly crystalline, and it is also dolomitic in composition, as is seen in the following analysis: (*Clarke.*)

Carbonate of lime	49.00
Carbonate of magnesia	38.59
Alumina and oxide of iron	1.51
Insoluble matter	9.22
Total	98.32

The only defect in its composition is its rather high percentage of impurities, as is shown in the 9.22 per cent. of insoluble matter, and this may be an accidental proportion.

The failure of Bryan apparently results from the deep descent of the Trenton limestone and not from its lack of capacity for storing oil or gas. It is interesting to note, as we are able to do from the analysis here given, that northwestward from Findlay and Lima the Trenton limestone maintains its dolomitic composition. To the east and south from the same district, as we know, its character is so far changed that it ceases to deserve the name of an oil-rock as it is followed in those directions.

If drilling is still persisted in by the people of Bryan and vicinity, it will quite likely happen that some larger folds will be discovered, from which a remunerative return may possibly be secured, so far as individual wells are concerned.

Hicksville.

The Hicksville Oil and Gas Company was organized in June, 1886, and begun work forthwith. This well, like the rest in this corner of the state, proved a great disappointment, both to company and contractors, by reason of the great amount of upper limestones, bearing salt-water, that the drill was obliged to traverse. The record of the well shows that almost the entire deposit of Ohio shale that is here due has been removed by erosion. The record, up to the present date, is as follows:

Drift	128 feet.
Black slate	4 "
Limestones—Upper Helderberg, Lower Helderberg and Niagara	868 "
Niagara shale	18 "
Clinton limestone	52 "
Medina shale at	1,060 "

The well will strike the Trenton limestone at about 1,670 feet.

Since writing the above, the well has been completed and the Trenton was found at 1,684 feet. The drilling was continued to 1,710 feet, where oil and salt-water were struck. The well filled up 300 feet, half of which was counted oil. The oil has a gravity of 36° B.

Defiance.

This enterprising and energetic town was moved early in 1886 to test its fortune, so far as the new horizon was concerned, fifty-six parties putting in $50 each. More money has since been added to this fund. The contractor who first undertook the work abandoned the well at 800 feet. The record, as furnished by Hon. Edward Squire, is as follows:

Drift	18 feet.
Black shale	60 "
Limestone struck at	78 "
Limestone, blue, at	80 "
Hard at	115 "
Bluish at	140 "
Hard rock at	150 "
Black slate	160 "
White limestone	200 "
Sulphur water, strong vein at	180 "
Limestone, coarse and soft	228 "
Soapstone at	270 "
Banded Waterlime at	340 to 700 "
Niagara, crystalline limestone called "sand" at	700 "
Sulphur water, strong vein at	720 "
Niagara limestone ends at	928 "
Niagara shale	928 to 980 "
Clinton limestone	980 to 1,040 "
Medina shale, grayish pebbles	1,040 to 1,062 "

The shales below the Medina are described as follows by Mr. George W. Doty, who completed the well:

Blue shale from 1,120 to 1,240	120 feet.
Black shale	30 "
Gray limestone	30 "
Black shale, very soft	35 "
Reddish brown shale, sandy	30 "
Dark, soft shale	70 "
Reddish brown shale	65 "
Black shale, like coal	10 "

Soft red shale	130 feet.
White shale	10 "
Trenton limestone struck at	1,670 "

Hard shell at 10 feet in Trenton.
Softer rock at 20 " "
Oil came in freely at 24 feet in Trenton.
Ran another bit and struck salt-water at ..... 1,687 feet.

Reduced to simpler terms, the record is as follows, viz.:

Drift	18 feet.
Ohio shale	60 "
Devonian and Upper Silurian limestones	850 "
Niagara shale	52 "
Clinton limestone	60 "
Medina, Hudson River and Utica shales	630 "
Trenton limestone, struck at	1,670 "

975 feet below tide.

The well stood several days before being torpedoed, the salt-water being kept down by bailing. There was thought to be 400 feet of oil and 100 feet of salt-water when the well was shot with sixty quarts of nitro-glycerine. The well responded favorably, as was thought, and quite a flow of gas appeared for the first time. The well remained in this condition for two weeks before tubing was introduced and the pump was set to work. The well yielded, when the test was made, little but salt water, and was forthwith abandoned. The Trenton limestone was found about 975 feet below tide. A second well was forthwith projected.

The details of this and other attempts to reach the new fuel at this point are not at hand, but there is nothing in any of them that deserves special mention. The public spirit of the town was fully equal to the search, but it could not secure from the rocks what they did not contain.

Napoleon.

Napoleon has had an unfortunate experience. A natural gas and oil company was formed early in 1886, and work was promptly begun, but the drilling tools have been fast in the well a good deal of the time, at one or another point, and they are now in this condition at the bottom of a fifteen hundred-foot hole. For a carefully kept record, verified by many samples of drillings, the Survey is indebted to Dr. T. C. Hunter, of Napoleon. This record is as follows:

Drift	Clay ..... 40 feet.		
	Gravel ..... 8 "	48 feet.	
Ohio shale.	Black shale ..... 75 "		
	Cherty rock ..... 11 "	106 "	
	Limestone	966 "	

Broken at 715 feet by 15 feet of black shale (Tymochtee), and at 1,010 feet by a few feet of Niagara shale.

The casing is set at 1,164 feet after having been previously set at a number of horizons in the vain hope of having gotten below salt-water. The drillers are now engaged in an effort to recover the tools. If they succeed, the well will probably be drilled to the Trenton, which should be struck at about 1,750 feet, or only 250 feet deeper than the well now is. The Trenton will be between 1,000 and 1,100 feet below tide.

The later records of this well show the Niagara shale to have been 25 feet, the Clinton limestone 95 feet, and the great shale series below it 660 feet in thickness, of which latter division 360 feet can be counted Hudson River and 300 feet Utica shale. The Trenton was struck at 1,780 feet, but it was hard and dry, and made little or no response. At 16 feet in the rock a little gas was reported, and at 33 feet a little salt-water. The well was continued to 1,889 feet, when salt-water was reported. The surface of the Trenton limestone was struck at 1,114 feet below sea-level.

A second well has been projected, but there is nothing to indicate any very different result from that already placed upon record.

Deshler.

The Deshler Oil and Gas Company began operations in the summer of 1886. A portable rig and a set of light tools were brought on the ground, and the progress has been very slow. The drill was ill-adapted to penetrate 500 to 600 feet of solid limestone in a wet hole. The drift was found seventy-one feet thick. The limestone, when first struck, was broken for some distance, and the seams were opened, evidently by pre-glacial erosion and exposure. At 245 feet the limestone became very hard and close. A bed of dark shale, fifteen feet thick, occurred below this level, and apparently at the same horizon reported in the previous record. It is provisionally identified with Winchell's Tymochtee shale of the Waterlime or Lower Helderberg series.

The well was at last completed in the summer of 1887. Its final record is as follows:

Drift	71 feet.
Limestone	610 "
Shale (Niagara)	5 "
Limestone (Clinton)	95 "
Shales	700 "
Trenton found at	1,485 "
Well finished at	1,600 "

Trenton limestone, 765 feet below tide.

At the summit of the Trenton an insignificant amount of gas was found, but the rock was close and stubborn and dry as far as it was proved.

Reviewing briefly the record of the wells of this corner of the state, the following facts appear: In Delta, the limestone series is 1,132 feet thick (this measure may be in excess somewhat); in Wauseon about 1,140 feet; in Defiance, 960 feet; in Napoleon, 966 feet; in Hicksville, 929 feet; in Bryan, 1,009 ft. The thickness of the lower shales in the wells which have completed their records are as follows: Defiance, 610 feet; Bryan, 665 feet; Wauseon, about 645 feet; Napoleon, 660 feet; Hicksville, 624 feet. This has proved disastrous ground for contractors. Not a well has thus far been finished by the parties that begun it.

Paulding county has recently completed a well, but all that is known of it is, that it is reported a failure.

The Trenton Limestone, as found to the South of Lima.

The counties of central, or southwestern Ohio, in which drilling has been done in the attempt to reach Lima oil or Findlay gas, will next be taken up.

Auglaize County.

Wapakoneta.

Wapakoneta, as was proper, made the first test for Auglaize county, beginning in the fall of 1885. Great delays were experienced, however, in getting the well down to the Trenton, owing to the difficulty of piercing through the heavy drift deposits by which the central regions of the county are covered. Two attempts to drive eight-inch pipe to the rock failed, but the third was successful. In the first well, the pipe was driven 153 feet, where a boulder was reached that formed an impassable obstacle. The next attempt was made at a small remove from the first location, but with almost identical results. The third location was a half-mile removed from the first. Here the drift was found 96 feet thick. The upper limestones were 192 feet thick. The Medina was found as red rock, ten or fifteen feet thick, and the Trenton was struck at 1,235 feet, or 348 feet below tide. The drilling was continued to 1,600 feet, no oil or gas being found in quantity in any part of the series traversed. Salt-water came in at the bottom and ended the fruitless search. A second well was afterward drilled by the energetic citizens of Wapakoneta, which repeated the history of the first.

St. Mary's.

The next well to be drilled in the county was one at St. Mary's. This town is located on the Lake Erie and Western Railway, and is on

the northeast line that connects Findlay and Lima. On this last-named fact, great expectations have been based. A company was organized early in 1886 with one hundred stockholders. The shares were $20, and were mainly held singly. Drilling was begun by Coe and Baughman, contractors, May 4, and the well was completed July 24. The well-head is 883 feet above tide, and the surface of the Trenton, 313 feet below. The drillers' record is as follows:

Drift	121 feet.
Upper limestones	194 "
Shales	880 "
Trenton struck at	1,195 "
The well was cased at	310 "

The Trenton was found hard and dry when struck. Under a cap of one and a half feet a flow of gas was reached, which was presently followed by oil. The gas was in force enough to lift the oil. A production of several barrels per day was delivered from the well, with some salt-water. On August 5th the gas escaping from the separator was measured, and the volume was found to be 58,080 cubic feet per day. This does not, however, indicate the entire gas-flow of the well. The total amount produced would not fall below 65,000, or 70,000 cubic feet per day. The well was torpedoed in Octobor with forty quarts of nitroglycerine, and the flow of gas was estimated to be increased 200 per cent. by the operation. The oil has a gravity of 38° B. These facts, viz., that oil was produced by the well, accompanied by gas enough to lift it, had their natural effect on the oil-producers of the new field, and land has been largely leased, in consequence, for drilling purposes.

A second well, known as the Hopkins well, was brought in on October 9th. It was drilled to 1,230 feet, and in less than five hours filled up to within twenty feet of the surface with salt-water, without either oil or gas.

A third well, known as Hopkins and Gordon's well, on the Graybill farm, was brought in, November 24. It found the Trenton at 1,132 feet. At ten inches in the rock, oil appeared. The drilling was continued for eight feet into the Trenton, and at the end of two hours 500 feet of oil were reported. The well was subsequently tubed and packed, and is reported as pumping fifty barrels per day. The record of this well is as follows:

Drift	110 feet.
Upper limestone	175 "
Shale	877 "
Trenton limestone found at	1,162 "
Present depth of the well	1,171 "

The well is located one mile south of the town, and one mile southwest of the Citizens' well, or No. 1.

The success of the Graybill well will direct a large amount of attention to this field, and development will henceforth go forward rapidly. (December, 1886.)

By far the most important facts pertaining to the St. Mary's field remain to be told. There has been developed here, during the first half of 1887, a gas-field of great present and prospective value. Further explorations have shown a considerable ascent of the Trenton limestone from the neighborhood of the village to the southward, and in these higher levels large accumulations of dry gas have been found.

The beginning of the later phases of this history goes back to the bringing in of a fine well by Gray Brothers and Scudder, on the Wm. Axe farm, N. W. ¼ section 30, on March 23, 1887. The elevation of the well-head is approximately 900 feet above tide. The Trenton limestone was struck at 1,138 feet below the surface, or 238 feet below tide. The drill rested at nineteen feet in the Trenton, where a natural flow of excellent volume was obtained. Measured on April 14th, at the casing, through a two-inch opening, an open pressure of six and one-half pounds was obtained. This stands for a daily production of 2,042,864 cubic feet per day. The temperature of the escaping gas was 51° F.

Valuable observations were made on this well as to measurements at the end of long pipes led out from the casing. The result of these observations is to discredit such measurements so far as their comparability with measurements at the well-heads is concerned. The friction of the pipes introduces new elements which cannot be left out of account in the calculation. These facts are perfectly understood by gas engineers, and this statement is necessary only because figures of production are current which are based on observations taken from one, two or three pipes at considerable distances from the well-heads. These measurements can be compared with others of like conditions fairly enough, but not with measurements made nearer the unobstructed flow of the gas.

This well was allowed to burn in the air for at least four months, and in that time it depleted the field to the extent of 250,000,000 cubic feet of gas. It has recently been purchased by the Lima Natural Gas Company, and is to be used in the supply of its lines.

The Watkins well, drilled and owned by the Lima Drilling Company, is situated two and seven-eighths miles east of St. Mary's. It is good for nearly 2,000,000 feet per day. From this well gas was first car-

ried to St. Mary's. When turned into the pipe it traversed the interval of two and seven-eighths miles in three and one-fourth minutes.

The Kellermeyer well, located in section 22, was drilled in soon after the Axe well. It is said to have reached the Trenton limestone at 1,092 feet. It is a valuable well, but is reported as somewhat smaller than the Axe well, previously described.

In August, 1887, the Haas well, located a half-mile east of St. Mary's, was finished, and it proved to be a valuable gas-well. The Trenton limestone was about 270 feet below tide in this well. Several other wells of similar production have been added to those already named.

The closed pressure of these wells is less than in the Findlay field, corresponding to the shorter column of water to which the pressure is to be referred. It ranges at about 350 pounds to the square inch. In the St. Mary's wells the gas-rock is about fifty or seventy-five feet higher in absolute level than the gas-rock at Findlay.

The gas-rock has not been analyzed, but its appearance makes it safe to say that it is a true dolomite.

Numerous failures have occurred in the vicinity, some wells being entirely dry, and others filling rapidly with salt-water when the oil-rock is reached. The salt water level appears to be about 325 feet below tide in this field.

The productive belt of the western portion of the township extends into Mercer county, and its development will be further described under the account to be given of that county.

The village of St. Mary's is sure to avail itself of the great advantages to be derived from so large and promising a supply of fuel at its own doors. Various manufactures are to be established here forthwith.

As an oil-field, St. Mary's township affords much less promise. Still a number of wells have proved fair producers. A well on the Warrington farm, N. E. corner section 11, flowed 100 barrels per day when first struck.

The two townships of Duchouquet and St. Mary's appear thus far to exhaust the possibilities of oil and gas supply for Auglaize county. German and Jackson townships have made repeated trials at the villages of New Bremen and Minster, but all these trials have proved failures. There are unusual accumulations of drift in these townships, which make the territory very dangerous for contractors. Long lines of drive pipe are required in any case, and there is always the liability to lose both labor and pipe after a great deal of work has been done. At New Bremen the Trenton Rock Oil Company found the drift 428 feet thick.

Just north of the county line, on the line of the canal, recent drilling has proved the presence of gas and oil in valuable quantity. In the vicinity of Spencerville the Trenton limestone has been reached at a depth of 330 feet below tide, and gas enough to supply the town is reported from a single well.

For the facts pertaining to this field, the Survey is greatly indebted to Hon. L. C. Sawyer, of St. Mary's.

Duchouquet Township.

This township has, for some time, been recognized as probably belonging to the Lima field. Little by little the driller has advanced his outposts, through Perry and Shawnee townships, finding wells of large yield in a scarcely broken series, until, at length, the county lines were passed. Two wells were drilled in October and November, 1886, one to the east and the other to the west of Cridersville. The first, or Sellers' well, came in on October 31st, and proved to be a productive well. The well of Cobb, Page & Co., to the west of Cridersville, found an excessive thickness of drift deposits. Drive-pipe was required for nearly 300 feet. This well, also, is productive.

A second well, drilled on the Layton farm near Uniopolis, in Union township, does not give as good promise in that direction. It was drilled twenty feet into the Trenton on October 30th, and made but a small showing. Deeper drilling and torpedoing worked no improvement, and the well was forthwith abandoned. (November, 1886.)

The leading facts as to the oil production of Duchouquet township have been given in connection with the history of the Lima field on a preceding page. This territory is recognized as equal in value to any part of this particular field.

Mercer County.

Celina.

Three wells have been drilled in Mercer county up to the present date, two in Celina, the county seat, and one at St. Henry's, near the south line of the county. Drilling was begun in Celina in the spring of 1886, and the first well was completed in June. An unusually valuable set of drillings was saved by Mr. Jacob Lauser, who was a member of the company engaged in drilling. The duplicates furnished by him made it possible to make a clear and sharp division of the driller's record

Drift		70 feet.
Niagara limestone	Yellowish limestone ..... 20 ft. White limestone, called marble..... 65 ft. Drab limestone ..... 9 ft. Limestone, various shades of color 41 ft.	133 "
Niagara shale		15 "
Clinton limestone		43 "
Medina shale, called rotten sandstone		20 "
Hudson River shale		480 "
Utica shale		310 "
Trenton limestone struck at		1,110 "
Or 235 feet below tide.		
Well drilled to		1,168

The well was dry. There was but a small show of oil, and the gas was in very small amount. The elevation of the well-head is approximately 875 feet above tide. The Trenton is found 235 feet below tide.

Notwithstanding this failure, a second well, which had been already projected, was pushed forward in another portion of the town. In the course of the drilling, a pocket of gas was found in the Hudson River shale at the usual horizon, which blew vigorously for a few hours, long enough to awaken great expectations, but which, like all these shale supplies, proved very short-lived and entirely without value. The Trenton gave no promise whatever, when it was reached. (October, 1886.)

Wells drilled to the south and east of Celina within the county limits have been successful in reaching very valuable accumulations of gas. A group of wells in the extreme eastern portion of the county must first be mentioned. The leading well in this series is one drilled in May, 1887, by the Trenton Rock Oil Company, on the Doenzes farm, section 24, Franklin township. Its record is as follows, viz.:

Drift	110 feet.
Upper limestones	160 "
(Cased at 275 feet.)	
Shales	860 "
Trenton limestone struck at	1,132 "
Well finished at	1,147½ "

The gas came in gradually at first, but one-half of the final supply was gained in the descent of a single foot.

In the upper limestones an extremely large vein of water was found, which flowed out over the surface of the country in a powerful current. It proved, after a little time, a source of unexpected danger to the country, from the reason that it tended to unwater the entire district, and thus to cut off the supply of fountains and wells on which the farmers had hitherto been able to depend. The oil and gas compa-

nies have thus far failed to appreciate the great importance of this subject, but their drilling rights will scarcely be held to cover the important factor of water supply for entire sections and townships, and especially the supply of parties who have had no dealings with the drilling companies. These great veins of water should by all means be confined in the rocks in which they are found, except as they may be required for use.

The Doenzes well is much the strongest that has thus far been drilled in this district. It showed, on May 31st, an open pressure of one-half pound in the casing, which stands for a daily production of 4,625,000 cubic feet per day. Two other wells in the immediate neighborhood are also reported as vigorous and the Axe well of Auglaize county is but a half-mile removed. This field is therefore to be counted of much promise. It is from these and nearer wells that Lima is to be supplied with natural gas during she present season.

Several other wells have been recently drilled to the south of Celina, which are reported as moderately productive of dry gas.

St. Henry.

An important well was completed early in November, 1886, about ten miles south of Celina, near the station St. Henry, on the C.V.W.&M. road, by Hon. Dennis Dwyer and other parties of Dayton. The well is located on the northwest corner of fractional Section 28, Granville township, on land belonging to Judge Dwyer. The tract in which it stands is a part of the so-called "Cranberry Marsh." The elevation is estimated at 950 feet above tide. The record, as furnished by Judge Dwyer, is as follows:

Drift	187 feet.
Upper limestone	110 "
Shales	859 "
Trenton at	1,156 "
Or 200 feet below tide.	
The well was drilled to	1,183 "

Gas was struck at six and one-half feet in the Trenton, the rock being dark-gray in color and porous in structure. No increase was noted for twenty feet. The well was then torpedoed, and the result was a very vigorous gas-well. A small amount of oil comes with the gas. This well was located and started by Judge Dwyer on the 45° line, or at least on the extension of the line joining Fremont, Fostoria, Findlay, Lima and St. Mary's. Seeing in a geological discussion of the new field some reflections directed against the reality of such structural lines as affecting gas and oil production in northwestern Ohio, Judge Dwyer determined

to make the test on his own property, which chanced to lie in the extension of this favorite direction. The success of the well was certainly unexpected, from the fact that dry holes had been put down all around it, at Union City, at Greenville, at Celina. The 45° line will be likely to receive new confirmation from this fortunate discovery, for in such fields only the successes are counted. The failures are soon forgotten or for them an adequate explanation is found.

This well was measured under rather unsatisfactory conditions, March 1, 1887. Access to the well was obtained through a two-inch pipe near the casing, but there was a back presure of fifteen pounds on the well, which could not be reduced with an opening of this size. The yield of the well, as thus found, was 2,635,200 cubic feet per day (at a temperature of 35° F.)

The closed pressure is said to be between 350 and 375 pounds per square inch.

This is manifestly a very important and promising addition to the gas resources of western Ohio.

Most of the permanent flow followed the effect of the torpedo. Before the well was "shot," the yield was insignificant.

A second well was forthwith begun by the same parties one mile south of the first location. It was brought in early in 1887. Its record is as follows:

Drift	134 feet.
Upper limestone	187 "
Shales	819 "
Trenton limestones at	1,140 "
First gas at	1,147 "
Second gas at	1,154 "
Well finished at	1,160 "

Level of Trenton limestone, 200 feet below tide.

The initial flow of gas was much stronger than in well No. 1, and a corresponding advantage was looked for from the effect of the torpedo.

The daily volume of the well before shooting was found to be 578,880 cubic feet. When closed the pressure rose to ninety pounds in two and one-half minutes. The torpedoing was done with sixty quarts of nitroglycerine, and the shot was successful in every respect, except in increasing production. Measured a short time after the explosion, the volume of the gas was found to be 1,117,800 cubic feet per day, or not quite twice the original volume. This was a disappointment to the company, but the well was still one of considerable value.

A very interesting addition was made to our knowledge of the composition of the Trenton limestone by this well. The fragments thrown

out of it by the effects of the shot were observed to be quite different in general appearance from the ordinary productive gas-rock of the field. The limestone was quite white and was highly fossiliferous, containing in identifiable state the characteristic fossils of this geological period. Submitted to analysis, it yielded the following results: (*Edward Orton, Jr.*)

Carbonate of lime	93.64
Carbonate of magnesia	3.87
Insoluble matter	1.27
Total	98.78

The explanation of the falling off in the production of well No. 2 from what seemed a reasonable expectation in regard to it was now made apparent. Its gas-rock is not of the largely productive type. This latter phase, as will be remembered, is always a dolomitic limestone with but little foreign matter.

The purity of this limestone will, however, be observed. In this respect it meets all the demands of a reservoir rock, the silicious residue being only 1.27 per cent., but instead of being a pure dolomite it is a pure limestone.

It is to be regretted that the failure to provide for chemical work under the Survey for 1887 has rendered it impossible to follow up as thoroughly as is to be desired the interesting and important questions that this anomalous and unexpected result has raised.

The gas-rock of the first well is presumably of the dolomitic type. Its appearance, at least, would place it in this category. The Trenton limestone of the second well represents a type that is found scattered throughout the entire field. It occurs in City well, No. 3, on the east side of Findlay, in the Carey wells, and also in the Dunkirk well. It is nowhere largely productive. It seems to represent portions of the original sheet that have escaped dolomitization, and it may well be that the altered rock is in close proximity to it.

The important conclusion announced on a preceding page, that all *large* storage of gas and oil in the Trenton limestone is confined to its dolomitic phases, is not only not vitiated by the unexpected composition of the gas-rock of well No. 2, but it rather receives striking confirmation from it.

Several other wells have been drilled in this vicinity of which good accounts are given. The territory bids fair to support numerous wells of 2,000,000 to 5,000,000 cubic feet capacity, and with a closed pressure of about 350 pounds to the square inch.

Fort Recovery.

From the extreme western side of Mercer county an unexpected addition is made to our knowledge of natural gas from the new horizons of northwestern Ohio. A well was drilled in the spring of 1887 at Fort Recovery, the history of which deserves special mention. The earliest record is as follows, viz.:

Drift	145 feet.
Upper limestones	75 "
Shale	185 "
Limestone and shale	110 "

Drilling was suspended at this point, not from choice but from necessity. Gas began to appear at 410 feet. It constantly increased as the drill descended until a depth of 490 feet was reached. A bed of fossiliferous limestone was struck at this level, which continued for 30 feet. The rock was almost entirely made up of the well-known and widely distributed shell, *Orthis testudinaria*. The stratum could be paralleled in hundreds of outcrops in southwestern Ohio. From this apparently unpromising source, such a flood of gas poured forth that it became impossible to continue the drilling. Water could not be poured into the well because of the force of the gas and the fragments of the brittle rock, broken by the tools, which were sent out in a storm that the driller could not endure. The supply was recognized as shale-gas, and its continuance was discounted for this reason. After two weeks, however, in which no diminution of the flow was perceptible, the volume was measured from a two-inch plug at the well-head. The average open pressure was found to be five and one-half pounds, and the daily yield was accordingly 1,814,400 cubic feet.

The gas was turned at once to some small account in the lighting of the town, but no attempt was made to guard or prolong the flow. If the gas were derived from a "pocket," it was deemed best to learn the fact.

In the course of a few weeks the pressure began to abate, and by mid-summer it had run down to zero. It can scarcely be doubted that the well furnished at least 75,000,000 cubic feet of gas in its brief career, enough, if properly husbanded, to serve the town for a number of years. It was found possible to get rid of it in three months.

When the pressure had abated, the well was deepened to the Trenton limestone, which was reached at a depth of 1,052 feet.

The experience of the field hitherto seemed to warrant the expectation that the main gas horizon would in this case prove prolific when found. Such was not the case, however, and the well was a failure.

A second well drilled north of the town also obtained a great supply of shale-gas, though not equal to the flow of No. 1, but here again the Trenton limestone proved unproductive, and a second failure in the field was registered. A third failure followed, the last well being located south of the town, and despite the brilliant promise of the opening chapter, the community is left without any better hold upon the new fuel than its proximity to the eastern and central wells of the county can give.

This experience seems to thoroughly discredit shale-gas. A better display of this product than the initial flow of No. 1 could not well be asked, and yet the two million feet of its daily yield have "gone glimmering" before a fourth of a year has passed.

The connection between gas in the shales and gas in the Trenton limestone, which the experience of Findlay seemed to establish, is proved to be illusory here. In fact, the experience of Fort Recovery, though unfortunate for its people, is replete with practical and scientific interest, and deserves to be carefully considered in the future search for gas in northwestern Ohio.

Shelby County.

Sidney.

Sidney, the thriving county-seat of Shelby county, has made an energetic and thorough search for Findlay gas within her town limits. Three deep wells have been drilled within or near the corporation lines. All of the deep drilling of the county has been done at this point. The first well was sunk by an association of 116 citizens combined under the name of The Enterprise Gas and Oil Company. The well was located at the southern extremity of the town. The drilling was carried on in the fall and winter of 1885. The Trenton was found at the depth of 1,205 feet, or 269 feet below tide. In it neither oil nor gas was found. It proved as dry and close as it ever occurs. The Hudson River series, however, yielded gas in considerable quantity at a number of horizons, but especially at 700 feet. At this point, as will be remembered, there is more or less accumulation generally found. This gas was struck December 8th, 1885, and very sanguine expectations were based on its vigorous flow. The gas from this horizon contains a much larger percentage of sulphuretted hydrogen than the gas derived from the Trenton limestone, and is correspondingly offensive. The well also yields sulphur-water in great strength and large volume from the upper limestones. The well maintained a feeble flow of shale-gas for several weeks and even months, but the quantity was insignificant.

A second well was drilled by the Miami Valley Oil and Gas Com-

pany, a corporation formed for this purpose, and consisting of fourteen persons. The well was located east of the business center of the town in the valley of the Miami River. It was begun on January 14th, and reached the Trenton on February 30th, at a depth of 1,205 feet. The Trenton yielded a little oil in its upper beds, and the well was carried farther in the search for more, being finished at 1,445 feet, where salt-water was reached in quantity. The well was cased at 250 feet. The Medina shale occurred in characteristic color here, but it was quite thin. The experience of the first well was repeated in this in almost all particulars, but a more vigorous and long-lived supply of shale-gas was found in this well than in the first. The gas horizons were as follows: at 475, 575, 650 and 720 feet, the last being decidedly the strongest. The gas from the well was measured April 21, 1886, and the yield was found to be 39,744 cubic feet per day. The well maintained itself fairly until the great storms of May, 1886, when it seems to have been overcome with the floods that fell and filled the ground. Its yield was permanently arrested at that time. The Trenton in this well is 267 feet below tide.

A third well was determined on by this ambitious and persevering town. The Sidney Gas and Oil Company located a well in the northern part of the town, and made another test of the Trenton in the summer of 1886. This company found, to its surprise, ninety feet of drift, showing an unexpected channel under the high ground on the northwest side of the town. Nothing more came from this than from the previous wells. An admirable set of samples of drillings was kept by the second company, and was by them kindly shared with the Survey. The record, as deduced from these drillings, is as follows:

Limestone, very white, cuttings marble-like, at		140 feet.
Niagara shale at	170 to	210 "
Clinton limestone	230 to	250 "
Medina shale at		290 "
Hard, fossiliferous band at		450 "
Ditto at		535 "
Gas vein at		865 "
Utica shale begins at		895 "
Utica shale, very black, at		1,015 "
Trenton at		1,250 "

A point of special interest is to be observed in connection with the elevation at which the Trenton was found in the well. As already stated, its upper surface was 267 feet above tide. At Piqua, the first station southward at which the level of the Trenton can be determined, it is found to be 307 feet below tide, but the normal dip of the Trenton is to the northward. In the twelve miles traversed between these points,

the Trenton should have descended forty to fifty feet. Instead of dropping lower, however, it has risen forty feet higher. This elevation indicates a slight transverse axis, from which the presence of gas could have been reasonably expected in advance of the drilling. The wrinkle or fold here referred to may connect itself with gas accumulation at other points, if it is found to extend further. No distinct traces of it have been noted to the eastward. (October, 1886.)

The elevation above referred to becomes a part of the Lima axis, as is seen from the later developments of the field.

During the summer of 1887, well No. 1 was drilled deeper, and although no gas was found in the Trenton limestone in it, it was concluded to shoot the rock heavily. As a result of the torpedo, a good volume of gas is reported, but just what its value or significance is cannot now be determined. It is scarcely probable that any return will be made for the large expenditures.

Several additional wells have also been drilled by the people of Sidney in and around the town, but one record describes all.

The composition of the Trenton limestone underlying Sidney deserves a brief account in this place.

Analysis shows it to contain, as follows: (*Lord.*)

Carbonate of lime	62.30
Carbonate of magnesia	28.30
Oxide of iron and alumina	4.40
Insoluble matter	3.60
Total	98.60

This composition, though not of the greatest promise in itself, is still compatible with respectable production, as is seen from some analyses from the Lima field, but its chief interest lies in the fact that the change from a dolomite to a limestone appears to have been begun at about this point.

Logan County.

Bellefontaine.

The Trenton limestone has been reached at two points in Logan county during the last year, viz., at Bellefontaine and Belle Center. The Bellefontaine well was begun in the spring of 1886, but was not completed until September, the tools being fast in the well for a number of weeks. For the record of this well the Survey is indebted to J. Q. A. Campbell, Esq. The well was located on the low ground west of the railway station, at an altitude of about 1,190 feet above tide. The geo-

logical section at Bellefontaine is of unusual interest, the Devonian shales occupying the high ground in an out-lier, and the entire series of Upper Silurian limestones being, of course, directly underneath. At the point where the well was located, however, the bedded rock had been cut away, and a deep drift channel with precipitous sides was revealed by the drill, as appears in the following record:

Drift	150 feet.
Waterlime and Niagara	384 "
Niagara shale	28 "
Clinton limestone and shale	67 "
Medina, Hudson River, and Utica	905 "
Trenton limestone struck at	1,540 "

Or 350 feet below tide.

The well was drilled to 1,590 feet, and torpedoed in the first six feet of the Trenton. A small vein of gas was released, but the torpedo did nothing to increase it, and the well was considered a failure.

Belle Center.

Belle Center drilled a deep well in the winter of 1885. The record, as furnished by Mr. J. B. Temple, is as follows:

Drift	40 feet.
Limestone, gray and yellow	140 "
" blue, shelly	25 "
" hard, white	35 "
" blue	25 "
" light-colored	20 "
" hard and blue	10 "
" white and hard	30 "
" blue	15 "
Shale, fine, sticky	10 "
" red	10 "
" drab	625 "
" dark	325 "
Limestone, hard and gray	145 "
The Trenton limestone was struck at	1,310 "

A small vein of gas was found in it. Six months after the well had been drilled, the blaze of gas from a one-inch pipe was four feet high. No oil was found, and the well has not been torpedoed.

Huntsville.

A well was drilled to the Trenton limestone at this point in the summer of 1887. Neither gas nor oil was obtained in valuable amount from the last-named stratum, but a fair volume of gas was obtained from the Utica shale, about 150 feet above the surface of the Trenton limestone. The well was shot with a heavy charge of nitro-glycerine in the

Trenton and it was thought at first that the flow of gas was much increased, but if this was the case, the increase does not appear to be permanent. Measured in July, the volume of the gas was found to be 72,000 feet. Another measurement, recently reported, gives 50,000 feet as the present volume. The gas appears to be falling away after the usual fashion of the gas of this horizon.

The record of the well, as kindly furnished by Capt. J. H. Harrod, secretary of the company, is as follows:

Drift		67 feet.
Upper limestones		318 "
Red shale		8 "
Gray shale		
Brown shale	840 feet	1,007 "
Black shale	150 "	
Trenton limestone at		1,400 "
Well finished at		1,460 "

Trenton limestone, about 285 feet below tide.

The uppermost 20 feet of the Trenton appeared to be fairly good oil-sand, and analysis bears out this opinion respecting it. Below 20 feet the Trenton assumed the white and flaky character which is to be counted the normal character throughout this region.

The analysis of the upper beds is as follows: (*Clarke.*)

Carbonate of lime	57.23
Corbonate of magnesia	33.16
Alumina and oxide of iron	3.15
Insoluble matter	4.41
	97.95

There is nothing in these figures incompatible with moderate production of gas and oil so far as our knowledge goes.

De Graff.

A deep well was completed at this point in June, 1887. The Trenton limestone was struck at 1,281 feet, and the well was finished at 1,356 feet. The surface of the Trenton limestone was 290 to 300 feet below tide. At 10 feet in the Trenton, a small vein of gas was found. The well was then torpedoed, 150 quarts of nitro-glycerine being used in the shot. A little oil appeared after the shot, and the flow of gas was much increased. The later fortunes of the well have not been learned. There is nothing in the experience of the towns nearest to this to warrant an expectation that really valuable results will be obtained in this immediate neighborhood. The main supplies of available gas here, appear to be those obtained from the shales above the limestone, and shale-gas,

even when found in large enough quantity to justify use, is known to be lacking in persistency.

Union County.

Magnetic Springs.

One deep well has been drilled within the last three years in Union county; but, strange to say, it was not drilled with reference to either gas or oil, but in search of a substance more easily reached in the rocks of Ohio, viz., salt-water. Mr. W. Murphy drilled the well during the years 1884 and 1885, at Magnetic Springs, in Union county, in search of mineral waters that could be turned to account in his sanitarium and bath-house. The record, as kept by him, is as follows:

Drift	40 feet.
Limestones	354 "
Blue shale	30 "
Red shale	60 "
Shales	1,116 "
Hard rock at	1,600 "

At 100 feet in this lower rock, bitter-water was struck in considerable quantity. Salt-water was found at 700 feet. This record is easily interpreted. The Medina appears in the red shale, 60 feet thick; the Trenton is unmistakable at 1,600 feet. Neither gas nor oil were discovered, and the water, though counted well adapted for the uses for which it was sought, was not delivered from the tube except as it was pumped. The thickness of the great shale formation is excessive, as reported; and possibly the drillings would have borne a somewhat different distribution if an opportunity had been secured for examining them.

Marysville.

The record of the well drilled at this point in May, 1887, is as follows:

Drift (gravel and gravelly clay)	106 feet.
Upper limestone (Waterlime and Niagara)	249 "
Slate (Niagara shale)	25 "
"Sandstone" of driller (Clinton limestone)	100 "
Red rock (Medina shale)	47 "
Gray slate (Hudson River group)	758 "
Black slate (Utica slate)	379 "
Trenton limestone, struck at	1,664 "
" solid	58 "
" slate and limestone	21 "
Well finished at	1,743 "

The Trenton limestone is between 600 and 700 feet below tide at Marysville. It was entirely destitute of value here. In fact, the whole

series was unusually barren of promise. It is condemned on a double count, by reason of its depth and also by reason of its composition.

Similar reports are due from Mechanicsburg, Milford Center and Fountain Park, where deep wells have been recently drilled. At Mechanicsburg, the drift is reported 280 feet thick, and the Trenton limestone is said to have been struck at 1,455 feet. It was of course unproductive.

Delaware County.

Delaware.

Delaware followed the prevailing fashion by drilling a deep well in the summer of 1887. The number of such drillings in this portion of the state had by this time become so great that it was easy to anticipate the result. The Trenton limestone as found here is in no sense an oil or gas-rock, no more so than any other limestone of the section that a deep well brings to light.

The record of the well, as kindly furnished by Mr. J. O. Johnston, the contractor, is as follows:

Drift	20 feet.
Upper limestones	710 "
Red rock, thin.	
Shales, blue and dark, to	1,788 "
Well finished at	2,130 "

There is some doubt as to where the Trenton limestone was first struck. It is credited to 1,788 feet, but it could scarcely have begun before 1,950 feet. The lower portion of the Utica shales are highly calcareous. The Trenton limestone in central Ohio is in all cases a white, or at least a light-colored rock.

The well was unusally barren of interest in the way of gas or oil, and the record is not even enlivened with an inroad of salt-water.

Prospect.

The experiment made at Prospect will be briefly reported here, though the town is beyond the limits of the county. (It is located in Marion county.) A well was finished at this point in July, 1887, at a depth of more than 1,650 feet. The drift was fifty-four feet thick and the upper limestone 400 feet. The Trenton limestone was found at this last-named level, which is about 750 feet below tide. Condemned by the unbroken law that a descent of more than 500 feet below tide is fatal in this part of the state to large accumulations of gas or oil, this region finds a pre-existent and insuperable barrier in the way of its being counted pos-

sible oil territory in the composition of the Trenton limestone which is the goal of every well. In the Prospect well it shows the following composition, viz.: (*Clarke.*)

Carbonate of lime	66.02
Carbonate of magnesia	3.77
Oxide of iron and alumina	2.57
Insoluble matter	26.12
Total	98.48

It is needless to say that no rock of this character will ever be found a source of oil or gas. How much territory is represented in this analysis, cannot, of course, be told.

A well drilled at Waldo, due east of Prospect, and a short distance north of the Delaware county line, gave a similar record and the stereotyped result of failure.

The well was begun in black shale territory and 100 feet of this formation were reported, which was followed by 725 feet of limestones.

Darke County.

Greenville.

Wells have been drilled to the Trenton limestone at two points in Darke county, viz., at Greenville and at Union City. Prof. J. T. Martz, superintendent of schools at Greenville, has kindly furnished a record and the samples of drillings from the well at this point. The well was finished in June, 1886. The main facts appear below:

Drift	89	feet.
Niagara limestone	82	"
Niagara shale at	260	"
Dark shale at	300 to 1,136	"
Trenton found at	1,136	"

At 1,148 feet, or twelve feet in the limestone, the rock was very hard and compact. Neither gas nor oil was found in it, nor indeed in the descent at any point in notable quantity. The well-head is about 1,055 feet above tide, and the Trenton is thus seen to be eighty-one feet below tide. Several noteworthy facts appear in this record. The first and most important is the high level of the Trenton limestone. It has risen quite rapidly from all the nearest stations at which its relation to sea-level has been determined. This point will be further discussed on a later page. Another point to be noted is the dark color of the Hudson River shales, as appears from the record, and also from an examination of samples of the drillings. From 300 feet downward to 1,134, the entire

shale formation is dark enough to be called Utica. Not another section of precisely this character has been observed in the rocks of Ohio.

At Union City, on the west line of the county, in this state, a well was drilled late in 1885. The record was furnished by Mr. George Given, contractor, and is as follows:

Drift	104 feet.
Limestone, soft near the bottom	180 "
Shales	864 "
Trenton limestone struck at	1,164 "

Or forty feet below tide.

Water abounding in sulphur and various salts (Blue Lick water) was struck at 1,630 feet. The well was finished at 1,784 feet, and was destitute of oil and gas. Here, too, the high level of the Trenton is to be especially noted. Instead of declining to the northward, as is usual, so that it should be 150 to 175 feet below the level of the limestone, as found at Eaton in Preble county, it was at precisely the same elevation as in the place last named, viz., forty feet below tide, and this shows a suppression of dip equal to the normal amount of fall. A similar fact has been pointed out in the Sidney well. The two facts may stand related to each other.

The composition of the Trenton limestone at Union City is as follows: (*Clarke.*)

Carbonate of lime	83.21
Carbonate of magnesia	12.48
Alumina and oxide of iron	1.23
Insoluble matter	2.14
Total	99.06

The small amount of insoluble matter in the limestone is a point in its favor, but no rock of this character and composition has yet been found productive of oil or gas in any notable amount.

Arcanum.

Two or more wells have been drilled at Arcanum. The first reached the Trenton limestone late in April, 1887, at a depth of almost 1,150 feet, or about 100 feet below tide. It produced a small vein of dry gas, which was considerably increased by the explosion of a torpedo at the proper level. The gas was forthwith utilized in the town. No authentic facts have been obtained as to the volume and pressure of the gas, but considerable local interest has been aroused. The well seems the best that has been obtained in several of the contiguous counties, but this statement does not necessarily give to it any particu-

lar value. The supply is doubtless one of the uncertain ones about which questions as to whether or not it pays for production can be raised, but the truth is that whenever such questions need to be raised, they have been already answered. A second well was finished in June, 1887.

New Madison.

The Trenton limestone, was found at New Madison, at a depth of 1,150 feet. An analysis of it is herewith given: (*Clarke.*)

Carbonate of lime	64.91
Carbonate of magnesia	17.98
Oxide of iron and alumina	3.60
Insoluble matter	11.11
Total	97.60

It is scarcely necessary to repeat the remark so often made that Trenton limestone of this type has little or no relation to gas or oil.

A well drilled at Ansonia was also a failure.

MIAMI COUNTY.

Piqua.

Two deep wells were drilled at Piqua during the first six months of 1886. Well No. 1 was drilled to the Trenton limestone in March for a company of citizens organized for the purpose of testing the Lima horizon at this point. The driller's record was not obtained, but from Mr. C. T. Wiltheiss, carefully kept samples of the drillings were received, by which a partial record of the well is established as follows: Niagara limestone, bottom beds struck a few feet below the surface, thirty-one feet thick; Niagara shale occurring as a blue clay with pyrite. Neither the Clinton limestone nor the Medina shale are noted in the record, although both were undoubtedly present in the well. At 365 feet in the Hudson River shales, and under a cap of hard fossiliferous limestone a pocket of gas was struck, which blew with great force for fourteen hours and then suddenly declined and died out altogether. Great excitement was caused by this outburst of gas, but there was nothing afterward discovered in the progress of the well to maintain this interest, inasmuch as the Trenton was hard and dry. The Hudson River shales were about 700 feet thick, and the Utica shale about 385 feet. The Trenton was struck at about 1,185 feet from the surface. Drilling was continued to 1,673 feet, or about 500 feet below the surface of the Trenton. Bitter-water and brine were found at last, as they

usually are, if the drill goes deep enough. The well was located at the south end of the town, and not far from the Piqua stone-quarries.

Well No. 2 was located on the east side of the Miami Valley, and not far from the station of the Dayton and Michigan Railway. It was drilled in June, 1886. The Trenton was struck at 1,175 feet. The well was torpedoed shortly after it was finished, and a small flow of gas was obtained. A few barrels of oil were also bailed out of the well. The oil was of low gravity, registering, when obtained, 34° B., but the test was not a fair one, as the oil had been previously exposed. The flow of gas was maintained for some time, but there was never enough of it to justify much outlay in an attempt to utilize it in any way. The well was drilled to 1,245 feet. The Trenton limestone was found here at a depth of 307 feet below tide-water. Several other wells have been drilled in and around Piqua, but the search appears to be without valuable results.

Troy, Covington, and Tippecanoe City.

Wells were drilled in the summer of 1887 in these three towns, with the stereotyped results of this part of the state.

Troy found no upper limestone. The drift beds were 133 feet thick. At 510, 680 and 880 feet, respectively, slight flows of gas were encountered. Brown shale (Utica) began at 680 feet, and continued to 1,030 feet, where the Trenton limestone was found 170 feet below tide. Salt-water was struck at 1,120 feet, or 90 feet in the Trenton limestone. The drilling was suspended at 1,170 feet.

At Tippecanoe City the Trenton limestone was struck at 1,025 feet, or about 180 feet below tide. In several of the counties last named, and from this district southward through the state, the boundary between the Utica shale and the underlying Trenton limestone becomes somewhat indistinct. Sheets of crystalline limestone are interbedded with the black shale for twenty to fifty feet at the bottom of the shale series. The first hard rock struck is generally taken by the driller for Trenton limestone, but the true boundary probably lies at a considerable distance below this mark. It seems safe to count the rock as Trenton in age when the beds of black shale have all been passed. The Utica, in its lower courses, is in all cases quite highly calcareous, so that no proper distinction can be effected by means of acid tests between it and the Trenton limestone.

CHAMPAIGN COUNTY.

Urbana.

Urbana has made three trials of the Trenton limestone within the last year. Well No. 1 was located at the tannery within the city limits,

at an elevation of 1,047 feet above tide. It was drilled in May, 1886. An excellent record of the well was kept by Prof. T. F. Moses, correlated and corrected by a great number of samples of drillings, and these have been kindly furnished by him for the use of the Survey. The record is as follows:

Drift	155 feet.
Niagara limestone	70 "
Niagara shale	25 "
Clinton limestone	53 "
Blue shale	15 "
Red shale, Medina	34 "
Blue and gray shale, Hudson River	689 "
Brown and black shale, Utica	300 "
Trenton struck at	1,350 "
Well finished at	1,730 "

Where salt-water was found at 380 feet below surface of the Trenton.

The amount of drive pipe was 158 feet. The well was cased at 308 feet. A small volume of gas was yielded by the Trenton at 1,350 feet. The well was shot from 1,350 to 1,400 feet, and the flow of gas was somewhat increased thereby, but there was not enough produced even then to justify any attempt at utilization. The surface of the Trenton limestone was 303 feet below tide. The leading members of the company were not satisfied with the results of this experiment, and forthwith formed a new company to make another test in the vicinity. The locality selected was on the Rattlesnake Prairie, two miles west of town, on the line of the Chicago, St. Louis & Pittsburgh Railway, and the well was known as the Rattlesnake well. It was drilled in July and August, 1886. The well-head was forty feet lower than the elevation of well No. 1, or 1,063 feet above tide. The record of this well also was furnished by Prof. Moses, and is as follows:

Drift	133 feet.
Niagara limestone	50 "
Niagara shale	21 "
Clinton limestone	51 "
Casing set at	270 "
Hudson River, or gray shale	800 "
Utica, or black shale	292 "
Trenton struck at	1,307 "

Or 304 feet below tide.

Medina, or red-rock, was found in small amount at 303 feet. A very vigorous "blower" of gas was struck July 21st in the Hudson River shale, at a depth of about 803 feet. The gas was delivered with great force, the flame from a two-inch pipe being estimated to be twenty-five feet long. It held on for eight or ten days with but small abatement, but ran down rapidly thereafter in pressure to zero, and

thus disappeared. The Trenton limestone was found entirely dry. It was drilled to a depth of seventy feet, then torpedoed and abandoned.

When the shale-gas "blower" of well No. 2 was struck, great excitement was caused thereby, and a few of the stockholders of the first well, who had not taken part in the organization of the second company, at once made arrangements to sink a third well intermediate between Nos. 1 and 2. This well was completed in September, 1886. A trifling quantity of oil was found in it, but it was as complete a failure as those that had preceded it. "Blowers" of gas of the same general character as that recorded in No. 2 have been found by all the towns in this vicinity that have drilled to this horizon of late. Among these towns may be named Sidney, Piqua, Dayton and Springfield.

Not recognizing the fact that these repeated failures had probably resulted from the change which the Trenton limestone had undergone in the interval between Lima and this pcint, by which it had ceased to be an oil-rock in any worthy sense, the search was still further prolonged in the vicinity of Urbana, and two or more records of failure were added to the list already reported.

St. Paris.

St. Paris is located on the summit between the Mad River and the Great Miami valleys. Its railroad level is 1,238 feet above tide, against 1,042 (1,030) at Urbana, and 884 at Piqua, or in round numbers, it is 200 feet higher than Urbana and 350 feet higher than Piqua. A small quarry is said to have been once opened about two miles south of the town, in the Waterlime formation. This fact, taken in connection with the elevation, led to the belief that a tongue of this stratum extends from its northern outcrops to the southward through the western part of Champaign county. On the geological map of the state, this view finds expression, but the facts of outcrop on which it is based must certainly be few in number.

The drilling mania, as it advanced through western Ohio, took possession of St. Paris in due time, and much encouragement was taken by the people from the recognition of the high level of the town. It was held that this elevation of the surface indicated a corresponding rise in the strata, and that probably the northward extension of the Cincinnati axis was to be found here. A contract for drilling to the Trenton limestone was let upon the usual terms, and work was begun in the spring of 1887. A depth of 100 feet of drift, or thereabouts, was anticipated, and drive pipe to this amount was provided. The pipe was used, but the drift was not exhausted. Another hundred feet was

added. The drift at this point consisted of gray clay, and the pipe was quite easily driven. Below this, blue, sandy clay was found, continuing to 300 feet. Driving pipe beyond 300 feet became monotonous. No drift section had heretofore been reported of so great thickness in the state. At 360 feet a tough, brown clay, that burned terra cotta red, was found. At 400 feet a genuine surprise was encountered by the driller. Gravel, containing large pieces of wood and bark, and also fragments of mussel-shells, was struck at this depth. The shells were scattered and no scientific examination was made of them, but the fragments of wood seemed to be the red cedar that generally occurs in our forest soils. At 405 feet the well filled up 150 feet with quicksand.

The contractor pushed on through difficulties and obstacles that it would be tedious to even enumerate. Once or twice it was thought that bedded shales were struck, but further progress revealed unmistakable boulder-clay, and the last samples raised from the well at 530 feet were of this formation. The upper limestones had all been worn away and their places supplied by this enormous deposit of drift materials. The bottom of the drive pipe stood in drift nearly 200 feet lower than the bed of the Miami River at Piqua, and 350 feet lower than the Mad River at Urbana.

The driller had unfortunately struck upon the ancient channel of the Miami River. The modern valley is largely in rock, which is the same as saying that it is of post-glacial origin. The old valley was known to lie to the eastward, but no conjecture had located it under this great dividing ridge.

The quarry stone, two miles south of the town, must stand up in a great wall, as high and nearly as abrupt as the most marked boundaries of the Ohio Valley at the present time.

At 530 feet, after traversing the deepest section of drift ever found in Ohio, the contractor retired discomfited, without reaching bedded rock. It was impossible to drive the pipe another foot.

Another location was selected by the company, eighty rods northwest of well No. 1, and bedded rock was reached at 370 feet. The upper limestones had been removed from this section also, and only shale separated the driller from the Trenton limestone. A small vein of gas was found at about 1,000 feet, but no extended report of the results of drilling is at hand. This silence is significant. Whenever there is anything to be told, publicity is always secured.

For the very interesting record of the drift beds of the first well, the Survey is under obligations to Dr. Charles Jones.

Clarke County.

Springfield.

Several wells have been drilled in Springfield in search of oil and gas from the Trenton, or from any other horizon that might hold a supply. The manufacturing interests of the town are so important that no price would be counted too great to pay for an abundant supply of the new fuel. The first well was sunk for a company of citizens in the fall of 1885, by Mr. J. W. Churchill. The record furnished by him is appended. The well was located on the floor of one of the quarries of the city. The geological identifications are obvious:

Blue limestone (Niagara)		15 feet.
White clay	3 feet.	
Soft limestone (Niagara shale)	40 "	43 "
White limestone (Clinton)		42 "
Red slate (Medina)		12 "
Shale rock	226 feet.	
Shelly rock and gritty shale (Hudson River shale)—gas found here	37 "	
Gray shale	305 "	698 feet.
Light shale	130 "	
Dark shale	230 feet.	
Red sand	76 "	
Black shale	24 "	330 feet.
Trenton limestone struck at		1,140 "

A vein of shale-gas was reached at one of the usual horizons. Its real significance, or rather insignificance, was not understood at the time, as Springfield was so early in its investigations. The excitement that has been so often recorded in the previous pages in connection with these "blowers" of shale-gas was experienced here, but this short-lived supply presently disappeared, and the Trenton was found without promise in its surface beds. A descent of several hundred feet did not improve the situation in any degree. The well-head was approximately 950 feet above tide, and the Trenton is thus found to be approximately 190 feet below tide.

Of three other wells drilled after this date in Springfield, no record has been obtained except as to the final results. All are failures, aggravated rather than relieved by the transient flashes of shale-gas which they have each in their turn displayed.

The cause of the failure is not far to seek. An analysis of the Trenton limestone from well No. 1 tells the story. The figures are as follows: (*Lord.*)

Carbonate of lime	80.78
Carbonate of magnesia	6.29
Insoluble matter	9.63
Total	96.70

There is reason to believe that the surface of the stratum has about the same character through most of the surrounding country. As so often repeated, this is not an oil-rock.

A few analyses of drillings from well No. 1 were executed for the Survey by Professor Lord. The results are here appended:

No. 1.	Hudson River shale	750	feet in depth.
No. 2.	" " "	800	" "
No. 3.	Utica shale	900	" "
No. 4.	" "	985	" "
No. 5.	" "	1,050	" "
No. 6.	" "	1,100	" "
No. 7.	Trenton limestone, surface	1,150	" "
No. 8.	" " 50 feet in rock	1,200	" "

	1	2	3	4	5	6	7	8
Carbonate of lime	15.61	13.79	10.17	27.99	36.82	69.95	80.78	84.01
Carbonate of magnesia	4.23	5.03	4.13	4.41	3.86	2.16	6.29	1.88
Insoluble matter	67.60	69.58	73.55	57.65	50.33	21.29	9.63	12.19

A fifth well, which was drilled in the summer of 1886, by the Champion Machine Company near their city shops, deserves a brief report, inasmuch as it has pushed its way to parts of our geological scale that are very seldom traversed. The well-head is about 1,000 feet above tide. The record of well No. 1 was repeated in this as in all of those that have preceded it. The Trenton was struck at 1,200 feet, showing its surface to be about 200 feet below tide. The well was cased at 250 feet, and the casing maintained the well in proper condition until not only the Trenton was reached, but had been penetrated for a number of hundred feet. At a depth of 1,850 feet a vein of salt-water was found, and was cased out. An eight-inch hole was carried down to this depth, and indeed below. Salt-water was struck at 2,000 feet. The casing was re-drawn and the well reamed down. Between 1,900 and 2,000 feet, fifty feet of sand was claimed by the driller. There is certainly nothing improbable in a deposit of this character, but no samples are at hand for an authentication of this claim. The St. Peters sandstone of the northwestern states comes in on this horizon. At greater depths, salt-water was struck in constantly recurring horizons. The casing was drawn and set again many times below 1,800 feet, but one or two days' drilling would, in every case, bring in a fresh stock of salt-water. From 2,000 to 2,400 feet there was a succession of very light-colored

magnesian limestones. Some were silicious, but carbonates predominated in all.

The well was purely an experimental one. There is not a known fact in the geology of the country that would lead us to expect gas or oil in these deep-lying strata. Furthermore, if moderate flows of gas had been discovered under a series of strata filled with salt-water from 1,850 feet downward for at least 500 feet, it is scarcely probable that their exploitation could have been effected with profit. It is to be regretted that so expensive an exploration could not have been made to yield some results of scientific interest, seeing that the work was entirely devoid of economic value, but the suspension of the field-work of the Survey in 1887 withdrew the opportunity to study the facts as they were developed.

A well was drilled in Pike township by parties from Springfield during the summer of 1887. It is known as the Northampton well, or the Mower well. One or two points are to be noted in its history. In the drift beds, which were ninety-three feet thick, a large body of gas was struck, but, like all such supplies, this was soon exhausted. The casing of the well was set at 200 feet. The Medina shale was thin, but of a characteristic color. At 728 and 850 feet, respectively, small veins of gas were struck. The Utica shale was black, and it exceeded 300 feet in thickness. The Trenton limestone was reached at 1,293 feet. It was entirely barren. The well was drilled to 1,380 feet.

New Carlisle.

A deep well was finished in this village in July, 1887. At 990 to 1,060 feet the Utica shale became a firm and calcareous rock, though still black in color. It was counted Trenton limestone by the contractor, but this determination cannot be granted. At 1,060 feet the real limestone was struck, where the white and flaky stratum that marks this horizon in southern Ohio appeared. No gas was found in the drilling of any value or significance.

Madison County.

London.

A deep well was drilled at London in 1887. The record is as follows:

Drift	155 feet.
Limestone (Waterlime and Niagara)	205 "
Gray slate (Niagara shale)	40 "
Limestone (Clinton)	70 "
Red rock (Medina)	20 "

Gray slate.....	165 feet.		
Limestone	25 "	Hudson River and Utica shales.....	1,095 "
Gray slate.....	715 "		
Black slate.....	190 "		
Trenton limestone reached at.....			1,585 "

About 550 feet below tide.

The interest of this well ceases with its record.

Franklin County.

Columbus.

Not content with the result of the deep boring in the State-house grounds, the record of which appears on page 107, a number of enterprising citizens of Columbus, inspired by a visit to Pittsburgh and an inspection of the wonderful advantages brought to that city by natural gas, organized themselves into a company, early in 1886, to drill for gas within the city limits. The well was located on the banks of the Olentangy, near the Wassall Sewer Pipe Works, and was begun in March. The well was completed in July, 1886, a depth of 2,020 feet having been reached.

The State-house well, referred to above, was drilled wet and with pole tools, and although its depth was ample to test the question of petroliferous supply in the rocks, its negative testimony was rejected by the company on the ground above stated. Its record, though supported as fully as possible by samples of the pumpings, is still very unsatisfactory. The currents of water entering the well, blended and intermingled the drillings from the various levels so that the individuality of the various horizons is mainly lost. Attempts made by the Survey to obtain some clues as to the boundaries of the formations by means of chemical analysis, have proved unsuccessful.

The new well, however, furnishes an excellent record. Through the courtesy of the company there was secured to the Survey authentic sets of drillings from the entire series that was traversed, and a number of important facts in the geology of the state were established on this record. Perhaps the most important fact was the discovery of the great thickness of the Lower Helderberg limestones (Waterlime). A thickness of 100 feet is all that previous to this time it had seemed necessary to claim, but this measure was increased more than threefold on the indubitable evidence of the drillings and rock fragments yielded by the well.

The presence of red rock of the fossil ore variety in the Clinton series, and also of intercalated shales in the same series, was first established here. All of these points have been of great service and value

in the interpretation of many subsequent records throughout the state.

The level of the well-head was 737 feet above tide. Though in territory where the Ohio shale is due, all the deposits of this formation had been previously removed by erosion, and also a few feet of the uppermost beds of the Devonian limestones. The record, in condensed form, is given below:

Drift	104	feet.
Upper Helderberg limestone (corniferous)	96	"
(Three feet of sharp sand found near bottom of this division.)		
Lower Helderberg limestones (Waterlime)	373	"
(Gypsum in quantity at 550 feet; sulphur-water at 573 feet.)		
Niagara limestone	49	"
Niagara shale	68	"
Clinton limestone and shale	120	"
(Contains several courses of red rock.)		
Medina shale—red	80	"
Hudson River shale—blue and calcareous	650	"
(A small gas vein at 1,500 feet.)		
Utica shale, dark, verging to black	375	"
Trenton limestone struck at	1,915	"
Trenton limestone, white and flaky	105	"
Drilling finished at	2,020	"
Trenton limestone 1,188 feet below tide.		

The well was cased at about 800 feet in the Medina shale. As the event proved, it might have been cased at 625 feet in the Niagara shale, no water being found in the Clinton series.

The well was barren of gas and oil to an unusual degree. The Lower Helderberg limestone was, as usual, quite petroliferous, but it gives rise to no accumulations. The drillings from 470 to 500 feet were examined for petroleum by Professor Lord, and nineteen-hundredths of one per cent. of the rock was found to be *petroleum as such*, being extracted from the pulverized rock by the proper solvents. Several hundred feet are represented by this analysis, and the total stock of petroleum to the acre is seen to be very large, though entirely valueless, by reason of its general and sparse distribution.

The Trenton limestone is far removed from its oil-bearing phases, as is seen in the following analysis: (*Lord.*)

Carbonate of lime	69.3
Carbonate of magnesia	4.3
Oxide of iron and alumina	2.7
Insoluble residue	23.6
Total	99.9

If it had proved instead to be the purest of dolomites, it is as good as certain that it would have been filled with salt-water, situated as it

is far down the eastern slope of the Cincinnati uplift. As shown in this analysis, the Trenton limestone of central Ohio is about as far removed from all possibility of oil or gas storage as any other rock in the entire geological scale of the state.

Westerville.

A deep well has been recently drilled at this point. The Ohio shale makes the surface-rock, and about 300 feet of it are said to have been found before the limestones were reached. Of the latter division there were about 700 feet. The Trenton limestone will be found here, according to this report, at 2,200 to 2,300 feet.

Sunbury.

The well now drilling at Sunbury must also be reported here, though it belongs in Delaware county. It was begun just below the horizon of the Berea grit, in the Bedford shales. The shale series is reported about 400 feet thick, and the upper limestones about 700 feet thick. The series is normal throughout. The Trenton was found at 2,530 feet, or thereabouts. A good volume of shale-gas was obtained in the first 300 feet of the descent, but nothing of economic value is reported from the lower strata. Household supply can doubtless be secured from the shales. No other known supply is available in this region.

In the accompanying section, from Union City to Columbus, some of the facts stated in the last few pages are represented.

MORROW COUNTY.

Cardington.

Though out of its geographical order, a brief account must here be given of a well drilled in 1887 at Cardington. The well-head is about 990 feet above tide. The record is as follows, viz.:

Drift			7 feet.
Black shale	10 feet.	Ohio shale	345 feet.
Soft blue shale	40 "		
Black shale	260 "		
Light-blue shale	35 "		
Limestone, corniferous			105 feet.
Salt-water rock			30 "
Black limestone			70 "
Gypsum			5 "
Hard buff limestone			50 "
Gypsum			5 "
Brown limestone			125 "
Shaly bed			20 "
Dark limestone			90 "

This record is unfinished.

The only peculiarity in the well was the fact that it yielded quite a volume of gas from the Corniferous limestone, a horizon from which little value has thus far been obtained in Ohio. Gas was derived from this same stratum at Chicago Junction, but it is generally unproductive. The further fortunes of the well have not been followed. The Trenton would seem to be due at about 2,300 feet.

Preble County.

Before the present interest in oil and gas had been developed, Preble county could lay claim to the best record of the deep rocks underlying it of any portion of western Ohio. In the wide-spread excitement as to petroleum that extended through the country twenty-five years ago, the surface indications of oil that abounded in the Clinton limestone in many of its outcrops in southwestern Ohio led to an expensive test of the rock at Eaton, the county seat. A well was drilled there to a depth of 1,375 feet. Both home and foreign capital were enlisted in this enterprise. Nothing of value was found in the descent of the drill. Although the records of the former experience had not been lost, the citizens of Eaton were desirous of making a new test with all the modern improvements in the art of sinking wells, and accordingly a company was formed early in 1886, and a well was drilled in June to the Trenton limestone. The record of the well was kindly furnished by J. R. Cook, Esq. It is as follows, the driller's divisions being adopted:

Upper limestone	40 feet.
Shale and limestone	460 "
Darker shale	530 "
Trenton struck at	1,030 "
Or about sea-level.	

A little dark oil was found at 300 feet in the Hudson River series, and a small quantity of light-colored oil at 1,200 feet, but the lower rock again proved to be in the main without either value or promise. From this point southward the Trenton limestone is found above the level of the sea. Wells have been drilled to it and below at several localities in Butler county, and at a number of points in Cincinnati and its vicinity, and also in the adjacent parts of Indiana. (December, 1886).

There have been drilled at Eaton during 1886–7 several wells in addition to the one here reported. The Ackerman well was carried to 1,607 feet and the Robinson well to 1,200 feet. Neither makes any return to the companies that have drilled them.

The New Paris well is also of the unproductive sort. The Trenton gas-rock does not extend within thirty miles of Preble county, according to present knowledge.

Camden.

The village of Camden, acting as a corporation, drilled a well within its limits during the summer of 1887. The record of the driller is as follows, viz.:

Drift	181 feet.
Blue shale (Hudson River)	283 "
Brown shale (Hudson River and Utica)	320 "
Limestone mixed with shale	56 "
Limestone, solid, at	840 "
Well finished at about	900 "

The Trenton limestone begins at 840 feet, though here, as elsewhere, the hard phase of the Utica shale was mistaken for Trenton, and the contractors' mark for the upper surface of this sheet was 784 feet. A vigorous vein of gas was struck soon after the shales were reached, viz., at a depth of 290 feet. Some accessions were made to it in the next 100 feet, but nothing was added below 400 feet.

The volume of the gas, measured before the well was completed, but several weeks after the flow was struck, was 74,520 cubic feet per day. The well attained a closed pressure of sixty-five pounds when shut in for one hour.

This entire volume could have been obtained by drilling less than 400 feet, and practically the whole amount could have been got within 300 feet. If a location were selected where the rock could be promptly reached, the expense of drive-pipe and casing could be avoided and the cost of a well could be kept within $300 or $400. It certainly seems worth while for the people of southwestern Ohio to make a full test of their possibilities in respect to the supplies of shale gas that underlie them.

Montgomery County.

Dayton.

The search for oil and gas in Montgomery and Preble counties dates further back than the excitement produced by the discovery of Findlay gas and Lima oil. Both of these counties were tested even to the depth of the Trenton limestone more than twenty years ago; and a negative report was brought back from these tests as to oil and gas being contained in the rocks that underlie. These records were, however, dismissed as unsatisfactory or were entirely forgotten, and new attempts have been made by both counties to discover, if possible, some stores of light and power in the deep-lying rocks of their geological scale.

Considerable drilling has been done at Dayton. A well of unusual geo-

logical interest, but devoid of economic value, was put down there during 1886–7. A natural gas company was organized in May, 1886, to make as thorough a search for oil and gas as a single drilling could possibly be made to do. The company consisted of thirteen business men, who put in at the outset $200 each, and who afterward liberally increased their subscriptions. Mr. George Wuichet is secretary of the company, and he has given a great deal of intelligent interest to the work that has been carried forward. The samples of drillings saved by him constitute one of the most interesting records ever furnished from the rocks of Ohio. The well is located on the southeastern side of the city, at the corner of Brown and Cemetery streets, and is in a quarry of the Cincinnati or Hudson River series. It is about 825 feet above tide. The well was begun nearly 200 feet below where the Lima and Findlay wells are cased A little surface water was found at first, and the casing was set at 425 feet, apparently at this depth through force of habit on the part of the drillers, who were from the Lima field. Several weak veins of gas were struck, as usual, in descending through this series, the most noteworthy of which were at 160 and 475 feet; the latter, in particular, acquired a transitory notoriety, but died out while its discovery was being reported. From a study of Mr. Wuichet's samples, combined with the record kept by the company, the following stratigraphical order is found in the section:

Blue limestone, Cincinnati group	420 feet.
(Gas at 160 and 450 feet).	
Blue slate, dark at bottom, Hudson River and Utica	415 "
Sand?	25 "
Limestone, interstratified with shale, Utica	80 "
Trenton limestone, white	30 "
Trenton limestone, 940 feet, or 115 feet below tide.	
Trenton limestone, blue	10 "
Trenton limestone, brown (Birdseye ?)	280 "
Limestone and slate	120 "
Salt-water at	1,370 "
(430 feet below surface of Trenton).	
White sand	10 "
White-rock, silicious, calcareous and magnesian	250 "
White-rock, magnesian limestones	760 "

The drilling was finally suspended at 2,440 feet, or about 1,600 feet below the upper surface of the Trenton limestone. A small gas vein was found a 2,128 feet, and considerable expense was undertaken in freeing it from the salt-water of these horizons. The attempts were unsuccessful. The first salt-water vein was struck at 1,360 feet, or 420 feet below the upper surface of the Trenton limestone; the second vein at 1,450 feet, or 510 feet below the same level. The water filled the

well within 200 feet of the top from this vein. It is much to be regretted that the suspension of the chemical work of the Survey has rendered it impossible to draw from the samples of these deep rocks the full measure of instruction that they can be made to furnish.

The composition of drillings obtained from two points in the descent, viz., at 1,390 to 1,400 feet below the surface, and again at 1,400 to 1,640 feet are given below: *(Lord.)*

	1	2
Carbonate of lime	50.56	34.14
Carbonate of magnesia	39.95	28.16
Oxide of iron and alumina	1.10	1.10
Insoluble matter	7.15	36.35

The first is seen to be a magnesian limestone, or dolomite of a common type, and the second is an impure magnesian limestone.

A number of interesting facts will be noted in this record: First, the Utica shale has been reduced in volume, at least as a black shale. The change from Springfield is quite abrupt. There are 300 feet at the bottom of the great shale column there as dark as at any point in northern Ohio, but here the dark portion is much reduced. It does not appear, in fact, distinctly in the record. The sand reported directly above the Trenton limestone is an unusual, if not an anomalous formation. Second, the upper part of the limestone series, or the lower part of the shale series, is a shaly mass eighty feet thick. The same line of facts is found in all of the wells to the southward and eastward, as for example at Middletown and Hamilton, Wilmington and Hillsboro. Streaks of shale are by no means wanting in the Trenton as found in northern wells, but there is not a distinct division of this sort as here. The reasons for considering this division in the Utica shale have been given on a preceding page.

The elevation of the Trenton limestone here is about 115 feet below tide, on the identification of this stratum as indicated above.

Drilling has been diligently continued at and about Dayton during the first half of 1887. Appreciating the immense advantage of even moderate supplies of natural gas at such a center, the business men who took up the search were unwilling to take no for an answer to the long and expensive questions asked of nature through the drill.

A well, drilled in the city at the corner of First and Findlay streets, in the summer of 1887, obtained a little more encouragement than most

of those before it, in the fact that a moderate vein of shale gas was struck at one of the ordinary horizons.

The elevation of the well-head is seventy-five feet above tide The record is as follows:

Drift, consisting mainly of gravel	247 feet.
Blue slate (Hudson River shale)	350 "
Darker shale (Hudson River and Utica)	200 "
Trenton counted at	870 "

This identification makes the Trenton 115 feet below tide. The vein of shale gas, obtained here, does not furnish any ground for encouragement as to large and persistent accumulations. The well was shot in the Trenton, but no change in the situation was affected thereby.

The insuperable barrier to success in this search is found in the character of the Trenton limestone as shown in the analysis of fragments of the surface of the stratum from this well. The results are as follows: (*Clarke.*) The limestone is seen to be in no sense an oil-rock.

Carbonate of lime	82.36
Carbonate of magnesia	1.67
Oxide of iron and alumina	.58
Insoluble matter	12.34
Total	96.95

Miamisburg.

Two wells have been drilled at this point during 1887, both of which secured considerable flows of gas in the shale series above the Trenton limestone.

Well No. 1, located on the north side of the town, was carried to a depth of 1,300 feet, where the sulphurous brine, which is known as Blue Lick water, entered in large volume and rose 1,000 feet in the well. This water was afterward plugged out for 400 feet above the bottom, and the gas that came in above was utilized in the paper mill near by. The pressure of the gas, as used, is found to be rapidly abating. The volume was measured on September 1, 1887, and found to be 26,827 feet per day. The well was drilled in on May 20.

Well No. 2 was carried to a depth of 800 feet only. Its gas, which is entirely derived from the shales between 370 and 670 feet, is in much larger volume than that of No. 1. An anemometer measurement on September 1, 1887, showed the daily volume to be 104,328 cubic feet, the largest volume yet observed in any well in southwestern Ohio.

The record is as follows:

Drift, mainly gravel..... 181 feet.
Casing set at 253 feet.
Blue slate..... 260 feet. } (Hudson River)..... 300 "
Lighter slate..... 40 " }
Dark shale, becoming black (Utica)..... 220 "
Gas at 370, 440, 575 and 670 feet.
The last flow, the most vigorous.
Courses of limestone come in at 750 feet and below, with some black shale.

The pressure of the gas when the well is closed rises about five pounds in one minute, attaining an ultimate pressure of sixty pounds. When first brought in the well showed a higher pressure.

It is clear that Miamisburg has not secured any valid promise of gas in large enough amount to serve its manufacturing interests, but domestic supply is possibly within its reach. All depends on the persistence of the shale-gas when properly guarded from waste.

Greene County.

The drilling epidemic was slow in reaching Greene county, but it broke out with considerable violence at a number of points during the summer of 1887. Xenia, Osborn, Jamestown and Spring Valley drilled wells to the Trenton limestone. Xenia, indeed, drilled two or more wells. It had already been made clear by the extensive exploration of the strata to the northward that there was no special promise in the Trenton limestone in this section of the state. Not a well south of Auglaize and Mercer counties had obtained gas enough from the Trenton limestone to justify the drilling, and scores of wells had found and reported the rock entirely barren. Moreover, the chemical clue as to the productive character or the want of it in the Trenton limestone, had already been obtained, and it was evident that while this great stratum extended as a universal sheet underneath western Ohio, the particular phase of it, which constitutes the oil and gas-rock, had been left behind 100 miles already to the northward. But it had also been demonstrated that more or less shale-gas was available throughout this region, and the wells that had been drilled were relieved in many cases from complete barrenness by obtaining these suspicious supplies.

When, therefore, these and numerous other towns of southwestern Ohio began their tests of the Trenton limestone in the summer of 1887, the outcome was as nearly certain as the results of such geological explorations ever are. Of shale-gas, whatever it is worth, moderate supplies were possible to the wells, but the Trenton limestone had ased to be a reservoir of oil or gas. Its composition is now expressed

by an altogether different formula from that of the Findlay and Lima dolomite. Instead of fifty per cent. of carbonate of lime, it contains more than eighty per cent., and instead of less than five per cent. of silicious impurities, it carries more than ten per cent. of such matter, and often fifteen or twenty per cent.

Xenia.

Drilling was begun in Xenia in June, 1887, by a Natural Gas Company. The record of the well was kindly furnished by Dr. A. H. Brundage. It is as follows:

Level of well-head			926 feet above tide.
Drift	Clay	6 feet.	94 feet.
	Gravel	20 "	
	Sand	35 "	
	Quicksand	25 "	
	Cemented sand	8 "	
Light-colored shales (Hudson River)			210 feet.
Dark shale (Hudson River and Utica ?)			325 "
Black shale (Utica)			32 "
Shell-rock—white limestone (Utica)			2 "
Black shale (Utica)			114 "

Limestone—white and solid, Trenton, at 1,040 feet, or 114 feet below tide.
Well drilled to 1,200 feet and abandoned.

A second company proceeded to drill, and a second record of the same sort was soon in its possession.

The paper-mill company obtained a small flow of shale-gas while drilling on its grounds for water.

A well is also in progress at the Powder-mills in the Little Miami Valley, above Xenia.

Osborn.

Osborn has obtained one of the best supplies of shale-gas in this portion of the state. The gas is derived from the Utica shale, and from a depth of 750 to 850 feet. The record of the well is given below:

Drift	207 feet.
Blue shale (Hudson River)	500 "
Darker shale changing gradually to quite dark or black shale (Hudson River and Utica)	213 "
Gray rock (pepper and salt-rock) Utica	70 "
Hard crystalline limestone (Trenton) at	990 "

At Troy there was forty-five feet of this last division, and at Tippecanoe City, twenty-seven feet.

The Trenton limestone is about 170 feet below tide.

The gas is said to be well maintained. Its discovery awakened great interest in this and surrounding communities. It is a matter of

regret that no measurements of the flow can be reported at this time. For the facts pertaining to this well, the Survey is indebted to S. F. Woodward, Esq., President of the gas company.

Spring Valley.

In the well drilled at this place the Trenton limestone was reached at 850 feet to 875 feet, making its elevation 100 to 125 feet below tide. The well was continued to 1,500 feet, where a flow of salt-water was struck that rose 800 feet in the well. The Utica division seems to be about 175 feet thick, including thirty or forty feet of limestones interstratified with black shale. Gas was not found in amount that deserves mention.

The facts pertaining to the well were furnished by Hon. I. M. Barrett.

Jamestown.

The Jamestown well was drilled to nearly 1,500 feet, and was heavily shot at or below the surface of the Trenton limestone. It filled with salt-water thereafter.

Fayette County.

Washington Court House.

A deep well has lately been drilled at Washington Court House, the county seat of Fayette county, the record of which can be appropriately given at this point. The elevation of the well-head is 965 feet above tide. The record, as furnished by Captain Allen Hegler, is as follows:

Drift	70 feet.
Limestone, blue, gray, white, shelly (Niagara and Clinton)	98 "
Shales, red, gray and dark	1,182 "

At 190 feet the gray shale formation was struck, which continued in belts of various color to 1,350 feet, where the Trenton limestone was reached. The elevation of its surface is 385 feet below tide. The well made but the smallest show of gas or oil, and the Trenton was, in particular, dry. Drilling was continued to 1,880 feet. Up to 1,850 feet the well was entirely dry, being protected from the time that the casing was set as far down as this point. The inroads of salt-water at 1,850 feet gave good reason for arresting the drill at this point.

Pickaway County.

Circleville.

A well has been begun at Circleville which will doubtless, in good time, reach the barren horizon to which it is directed, viz., the Trenton limestone. The section, as far as completed, is as follows:

Drift	140 feet.
Ohio shales	160 "
Devonian and Upper Silurian limestones	470 "

If the limestone series is completed already, as the contractor believes it to be, the shortest section of the state is found here. It is possible, however, that the shale in which the casing now rests is the Niagara shale, and that a considerable addition of limestones will be made in the Clinton division.

The section afforded by the well now in progress at Chillicothe may also be mentioned at this point.

There are found in drilling here—

Ohio shales	400 feet.
Limestones (Upper Silurian)	510 "

The work is still going forward. It must be confessed that these sections support each other and render probable the construction suggested above. In any case it is certain that there is a considerable reduction of these upper limestones in southern Ohio. They increase progressively to northwestern Ohio, where the total section exceeds 1,100 feet. In much of southern Ohio the section is reduced by the entire disappearance of the Devonian limestone, which is lost by overlap to the south of Pickaway county.

Butler County.

Hamilton.

The drilling at Hamilton has been conducted in a most judicious manner, and without any needless expense thus far. Work was begun by a number of the citizens associated for this purpose in the summer of 1886. The well was located in the gravel terraces of the Miami Valley near the city gas-works. The record is as follows:

Drift	Gravel	185 ft.	200 feet.
	Clay	15 ft.	
Blue shale			236 "
Brown and black shale			34 "
Limestone, interbedded with shale			80 "

The probable place of the Trenton limestone is at the bottom of the well, or about 550 feet below the surface.

This would make it fifty to seventy feet above tide. Gas was found in the same horizon as at Middletown, viz., at the summit of the brown or Utica shale. A small but persistent flow has been maintained from the well since it was first struck. Some of those who were interested in the drilling think that the gas was increased when the Trenton was reached. In August, the amount at the well-head from a two and one-fourth-inch opening was 30,000 cubic feet per day. The pressure rose at this time, when the well was closed, twenty pounds in five minutes. The rapid thinning of the black or brown shale which has been demonstrated to be the Utica shale of the general column, and which has been followed from the shore of Lake Erie to the present point in unbroken section, is especially to be noted. From 300 feet at Springfield, it is reduced o 100 feet at Middletown and 34 feet in the Hamilton well. It would seem from these facts that the Utica shale does not extend to the parallel of Cincinnati in its characteristic form. The same eighty feet of interbedded limestone and shale that was first found at Dayton and Middletown are again reported here. They are counted with the Utica shale for reasons previously given. The drill became fast at 550 feet, or just where the solid and light-colored limestone begins. No money, as has been already stated, has been wasted at Hamilton, and a household but not a manufacturing supply of gas has been indicated. The discovery of such a supply is not to be lightly esteemed. (December, 1886.)

The subsequent experience of Hamilton must be briefly described. A natural gas company was formed by a number of enterprising citizens early in 1887, to drill three wells in and around the town, in order to settle definitely the question that concerned them so much, whether a supply of rock-gas, adequate to manufacturers' use, could be found in the strata underlying them. One well was located on the east side and one in the center of the town.

Well No. 1 was drilled 700 feet without result. The record of well No. 2 is as follows:

Drift—mainly valley gravels	214	
Light-colored shale (Hudson River)		"
Dark shale (Utica)	76	"
Black shale and limestone (Utica)	70	"
Gray limestone (Utica)	10	"
Black shale and lime (Utica)	40	"
Trenton limestone—due in 40–50 feet, at	550	"

This well was also very dry. Its record is left incomplete.

A well was also drilled in West Hamilton during the summer of 1887, the record of which agrees with those already given. The well of 1886 is the only one of the list that has yielded a notable amount of gas. It has not been handled with care, and it is no longer counted of any value.

This courageous search will probably terminate at this point an with this experience. There is absolutely nothing to warrant furthe expenditure in this direction. The possibilities have been sounded and there is no promise of high-pressure gas to this portion of the state.

Oxford.

The well drilled at Oxford in the summer of 1887 must be described in few words. An excellent record of it was kept by Prof. Joseph F. James, of Miami University, and published by him in *Science*, June 24, 1887. It is as follows:

Drift	40 feet.
Blue limestone and shale	360 "
Gas at 302 feet.	
Blue shale	380 "
Black limestone	50 "
White magnesian limestone	450 "
Dark limestone	45 "
Arenaceous limestone, containing sulphur-water	40 "
Well finished at 1,365 feet.	

The first two divisions below the drift are obviously the equivalents of the Hudson River group as exposed in southwestern Ohio. The black limestone is the only representative of the Utica shale that appears here. The reference of this stratum to the Utica horizon is supported by all the facts obtained to the northward. The Trenton limestone was struck at 830 feet, or about seventy feet above tide-water. Sulphur-water, probably also more or less saline, was struck at 535 feet below the surface of the Trenton limestone. The last-named stratum has none of the characteristics of an oil or gas-rock at this point. The shale-gas was afforded in but a scanty supply.

Middletown.

The first of the wells drilled at Middletown will be briefly described. Drilling was begun at Middletown early in 1886, and the well was completed in June, a number of citizens combining in the enterprise. The well was located in the Miami Valley, and fortunately at a point where the bedded rocks were easily reached. The record, as furnished by Hon. William Caldwell, is as follows:

Drift	10 feet.
Blue limestone	130 "
Gray shale	310 "
Black shale	100 "
Limestone mixed with shale	80 "
Trenton limestone struck at	630 "

Or 37 feet above tide.

The lowermost eighty feet of the Utica were intermixed with limestone, as also reported at Dayton. The boundary of the Trenton is fairly distinct below. Thereafter, for 500 feet, the rock was solid, changing occasionally in color by a few shades. The drill was stopped at 1,060 feet. Salt-water was reached in the lower part of the well, rising fifty feet per day until within eighty feet of the top. It was finally shut off by a plug set at 665 feet. Veins of gas had been struck at 180 feet in the well, in the Hudson River shales, and again at 420 feet, or at the top of the Utica shale. This vein, although weak, seems fairly persistent. Measured in October, the flow was found to be 10,000 cubic feet per day, making a well that is described in the language of the directors as "not good enough to keep and too good to throw away." The danger in such supplies is that they cannot endure the natural shrinkage that all gas wells must be prepared for without becoming extinct. A volume of gas like that now reported would be abundantly worth drilling 500 feet for, if there were a fair prospect of such a degree of continuance as may reasonably be expected for this volatile fuel. The natural gas supply of Middletown will not, according to the results of this drilling, prove adequate for manufacturing uses; but if shallow wells can be found to yield household supplies with reasonable steadiness, the money spent in exploration will have been well used, so far as the interests of the town are concerned. The noteworthy facts in the record are the limited depth of the black (Utica) shale, and the intercalation of limestone in its uppermost eighty feet.

The statements of the preceding paragraph were made ten months ago. The gas was presently utilized, and it is stated that the flow of the well is fairly maintained to the present time.

Warren County.

Lebanon.

The annals of the search for gas or oil in the Trenton limestone of Warren county are happily short and simple. A well was drilled at Lebanon in 1887, the full record of which is not at hand, but it is known that the total depth exceeded 1,300 feet, and that salt-water was found in quantity at or near this point. The Trenton was unproductive and no large amount of shale-gas was discovered here.

A second well was drilled three-fourths of a mile west of the first location, in the valley of Turtle Creek. An unusual section was obtained here, so far as one element is concerned, as will be seen below. The record is as follows:

1.	Drift, mainly gravel and sand	256 feet.
2.	Blue limestone and shales	244 "
3.	Dark shale,	
4.	Dark slate and limestone,	162 "
5.	Hard white limestone	38 "

An abundance of slightly chalybeate water was found in the gravel. Gas was found at 330 feet and again at 360 feet, but not in large quantity.

Numbers 3 and 4 probably stand for the Utica shale. The Trenton is to be recognized in the white limestone at 662 feet. This would make it about thirty-eight feet above tide.

The facts pertaining to these wells have been kindly furnished by Josiah Morrow, Esq.

Clinton County.

Wilmington.

A well was drilled at Wilmington in the summer of 1887 to the Trenton limestone. The record was preserved with care by Professor Reynold Janney. It is given below, in part:

Drift	84 feet.
Niagara shale	5 "
Red rock—Clinton fossil ore	3 "
Clinton limestone	15 "
Brown shales (Medina)	5 "
Hudson River shale, about	850 "
Utica shale, interbedded with limestones	
Trenton limestone	

New Vienna.

Through the kindness of Dr. Geo. R. Conard, an excellent record of the well drilled at New Vienna to a depth of 1,788 feet was obtained. The record was supported by an admirable set of drillings, and thus the New Vienna section becomes an authoritative one for all this portion of the state.

It is not necessary to spread this record out in full, but the salient points will be indicated:

Clinton limestone, red	170 to 175 feet.
Clinton limestone, gray	20 "
Hudson River shales	780 "
Utica shales and interbedded limestones	246 "
Trenton limestone struck at	1,226 "
(About 100 feet below tide.)	
Salt-water struck at	1,785 "
(Or 560 feet below surface of Trenton.)	

Many alternations are shown in the samples of the limestones, but from 1,226 feet down, all are magnesian and almost all are light-colored. In the lower portion, viz., the beds at 1,650 feet, the bird's-eye mark is quite distinct.

The composition of the upper sheet of the Trenton is as follows, viz.: (*Clarke.*)

Carbonate of lime	82.43
Carbonate of magnesia	3.19
Insoluble residue	8.47

The character of the division called Utica may profitably be shown in greater detail. Gray rock, 1,048–1,120; black shale, 1,120 to 1,200; very black shale, 1,200–1,226.

The village of Sabina has also drilled, or is now engaged in the work.

Highland County.

Hillsboro.

A deep well was drilled in Hillsboro during the summer of 1887, and an excellent record of it was kept by Dr. H. S. Fullerton. The series traversed by the drill contained no unusual features. The Trenton limestone was struck at 1,200 feet. The analysis of the upper beds of this stratum is given herewith:

Carbonate of lime	85.00
Carbonate of magnesia	2.00
Oxide of iron and alumina	0.60
Insoluble matter	11.80
Total	99.40

Drilling was continued to 1,750 feet, where, at a depth of 550 feet below the upper surface of the Trenton limestone, the peculiar salt-water known as Blue Lick water was struck. The surface of the Trenton limestone is somewhat less than 100 feet below tide-water at this point.

Hamilton County.

Cincinnati.

It is to be regretted that while more deep wells have been drilled in and around Cincinnati than at any other point south of Lima, there is a less satisfactory record of the geological section here than can be obtained in almost any other county of western Ohio. Part of the drilling reported preceded the discovery of Lima oil, and part of it has been carried on with no reference to oil or gas, but in the seeking of quite a different element, viz., water for economic uses. The Cincinnati Gas Company has been prominently engaged in sinking these deep wells, its sole object being to obtain the artesian water that they yield for use in elevators. The Hemingray glass works, of Covington, has probably made the fullest and most careful test of the underlying rocks for gas or oil that has been made in the vicinity. The well sunk by this company was begun 44 feet above low water, or 476 feet above tide. It was carried to 2,007 feet, which makes it deeper, geologically, than any well yet drilled in Ohio. The Trenton was probably struck at about 300 feet, so that its upper surface is 175 to 200 feet above tide. The drift was 70 feet thick where the well was located. Gas, in weak supply, was struck at 170, 232 and 500 feet. At the latter horizon, water rank with salt and sulphur appeared in quantity. It is popularly designated "Blue Lick water," and the following analysis indicates its character: (*Lord.*)

"*Blue Lick Water,*" *Hemingray Well, Newport, Ky.*

	Grains to gallon.
Chloride of sodium	614.C4
Sulphate of lime	106.01
Chloride of magnesium	54.17
Silica	00.41
Alumina and iron	Trace.

Sulphuretted hydrogen, undetermined.

Larger supplies of water were found at 1,650 feet. The section was composed through its entire extent of calcareous rocks, the only exception being a 3-foot stratum of sand that was found at 1,100 feet. The drillers, it is true, reported sandstone by the hundreds of feet, but all that is thus reported disappears under adequate test, except the bed just named. From the record of one of the gas company's wells, from which samples of the drillings have also been carefully preserved, and to which access was kindly furnished, the following facts are gained:

Driller's Record.

Drift	120 feet.	
Soapstone	3 "	
Limestone	90 "	213 feet.
Sandstone	5 "	218 "
Limestone	380 "	598 "
White limestone	240 "	838 "
Sandstone	68 "	906 "
Hard limestone	15 "	921 "
Red sandstone	62 "	983 "
White sandstone	85 "	1,068 "
Coarse sand and lime	15 "	1,083 "
Sandstone	140 "	1,223 "
Hard, flinty limestone	250 "	1,473 "

The sandstones reported here can be safely relegated to the limestone column in almost every instance. They are simply hard or impure phases of the ordinary limestones, and contain more lime and magnesia than sand. The sixty-five feet of sandstone, reported from 838 to 906 feet, is the principal exception in the column. It contains, as reported by Professor N. W. Lord, the following elements, viz.:

Silica	67.15
Iron and alumina	16.82
Carbonates of lime and magnesia	12.79
Total	99.95

This stratum will answer very well to the St. Peter's sandstone of the northwestern states. With it would be included a number of the strata distinguished in the record as sandstones down to 1,000 feet. The limestone reported at 1,245 feet has the following composition: (*Lord.*)

Silica	17.40
Alumina	4.53
Oxide of iron	.86
Carbonate of lime	62.89
Carbonate of magnesia	5.64
Total	99.32

The limestone reported at 123 feet, of ninety feet in thickness, is doubtless interstratified with shales. It belongs to the Hudson River series. The great sheet of limestone which is represented as underlying it, 380 feet thick in the record, has the composition shown below, so far as reliance can be placed on the analysis of a single specimen of the drillings: (*Lord.*)

Silica	12.95
Alumina and iron	5.04
Carbonate of lime	78.70
Carbonate of magnesia	1.93
Total	98.62

The drilling recently done within the city limits and adjacent thereto has, however, thrown more light on the order of the strata than that previously reported. The record of a well sunk at the corner of George street and Freeman avenue in the summer of 1887, as reported by Dr. Walter A. Dun, is as follows:

1.	Drift	48	feet.
2.	Blue limestone and shale	54	"
3.	Blueish, drab limestone, very hard	20	"
4.	Blue limestone and shales	50	"
5.	Black brown calcareous shale	47	"
6.	Limestone, gray, with dark beds interstratified	73	"
7.	Black brown shale	15	"
8.	White compact limestone, with greenish beds, at	327	"

The progress of the well was carefully watched by Dr. Dun, and his record throws more light on the stratigraphical divisions than all previous records.

The most probable reference of these several elements on stratigraphical grounds seems to be as follows:

Nos. 2, 3 and 4	Hudson River group.
Nos. 5, 6 and 7	Utica shale.
No. 8	Trenton limestone.

According to this view, the Utica division is here 135 feet thick, and the surface of the Trenton limestone is 184 feet above tide.

A few more careful and discriminating records from this corner of the state are greatly needed. With such records in hand, comparisons of the series found here would be possible that would remove any anomalies that now appear and that would establish the absolute continuity of the main stratigraphical elements of the section.

Clermont County.

It will be remembered that the only natural exposure of the Trenton limestone that occurs in the state is found at Pt. Pleasant, in Clermont county. The character of the rock as it is seen here has already been described. It is about as far as possible from an oil-rock in composition and structure, and there is nothing whatever in its character or association to suggest that the same stratum a hundred miles

away may become one of the great petroleum and gas reservoirs of the country. The oil rock of Lima is on the horizon of the Pt. Pleasant quarry stone, but it is a very different rock from that in mineral composition.

Any attempts to find a supply of oil or gas in this stubborn limestone within the limits of Clermont county would seem preposterous in the light of the facts above given, but still several wells have been recently drilled here under the impulse arising from the discoveries of northwestern Ohio. The drilling done at the village of Felicity is the best-known and most successful in this portion of the state. A brief and imperfect account will be given of it at this point.

Felicity.

Drilling was begun at Felicity in the summer of 1887. The Trenton limestone was probably struck at about 400 feet. Before reaching it, however, quite a vigorous gas vein was struck. The Trenton limestone was drilled through for several hundred feet, but no additions were made to the gas after the shales were passed. The gas is said to maintain its pressure and volume thus far, and is to be utilized in the village. The well has not been measured by the Survey, and no just estimate can be made of its capacity or value. The gas is without doubt derived from the shales.

BROWN COUNTY.

Ripley.

A well recently drilled at Ripley is understood to have penetrated the deep-lying strata, as its neighbors have all done, and with the same negative results that most of them have reached. It is not known that there is any value whatever in this well.

The Trenton limestone has been reached in three other counties of Ohio during the last year. In many other counties, indeed, attempts to reach it have been made, but the adverse conditions, arising from excessive depth and from salt-water in the Upper Silurian limestones, it has been found impossible to overcome thus far, except in the three instances now to be named. In the preceding pages of this chapter accounts have been given of wells that have been drilled to this formation in every county of Ohio in which the surface rocks are not later than Devonian in age, except two. Adams and Pike counties are not known to have reached or even to have undertaken to reach the new horizon, but in all the others, and the list includes all the counties in

the western half of the state, the descent has been undertaken and accomplished, and records more or less complete have been furnished of the strata traversed by the drill.

It remains to give an account of the only two successful attempts to reach the Trenton limestone from territory occupied by Subcarboniferous and Carboniferous rocks. In Huron and Richland counties, wells located upon or within the outcrops of the Berea grit, have been sunk to the Trenton limestone, and in Lawrence county the still more difficult task of reaching it from the horizon of the Lower Coal Measures has been accomplished.

Huron County.

Plymouth.

A company was organized at Plymouth in the early summer of 1886 to test the rocks underlying the town as to their gas-bearing character. Work was begun soon thereafter, and was continued without prolonged interruption for nearly one year, or until May 5, 1887, when drilling was suspended at a depth of 3,020 feet. The Trenton limestone was reached on April 27, 1887, at a depth of 2,900 feet, or 1,910 feet below tide. The level of the well-head is 990 feet above tide. The record is as follows:

Drift		12 feet.
Berea grit		40 "
White shale (soapstone) / Red rock ..... 170 ft.	Bedford	210 "
Black and blue shales alternating (Ohio shale)		438 "
Devonian and Upper Silurian limestones		910 "
Shales, blue and red (Clinton in part? and Medina)		250 "
Shales, gray and blue (Hudson River)		600 "
Shales, dark and finally black (Utica)		540 "
Trenton limestone, struck at		2,900 "
Trenton limestone		120 "
Well finished at		3,020 "

Salt and sulphurous water was struck at 850 feet. The well was cased at 916 feet, and strange to say, this casing protected the well to the end of the drilling. The Utica shales have an excessive thickness, the largest measure, in fact, recorded in the state. The entire shale series, Medina, Hudson and Utica, aggregate 1,390 feet. This is a greater measure by about 300 feet than could have been expected from any previous records in this general region.

The Trenton limestone was particularly dry. Its composition is as follows: (*Lord.*)

Carbonate of lime	67.50
Carbonate of magnesia	11.40
Oxide of iron and alumina	2.60
Insoluble matter	16.60

The barrenness of the rock is sufficiently explained by this result.

There was nothing to break the monotony of the descent, and it required great courage and persistency to keep the tools in motion. It is to the credit of the company that they held out to the end. The record of the well, careful and accurate as it is known to be, is certainly valuable for instruction, and deserves to be well considered by the towns that lie still farther east before they undertake an even longer descent than Plymouth was required to make.

Dr. R. D. Sykes took the temperature of the well at various depths with the following results, viz.:

71¼° F. at	1,400 feet.
90⅗° F. at	2,800 "
92⅘° F. at	3,000 "

Of the methods employed in the observations no notes are at hand. The increase is below the normal rate.

Richland County.

Crestline.

Of the deep well drilled at Crestline, our knowledge is less complete, but the essential facts are as follows: The well-head was about 1,155 feet above tide, and the surface of the Trenton limestone, which was struck at 2,832 feet, is about 1,677 feet below tide.

The following record, furnished by Mr. J. H. Taylor, who had supervision of the drilling, puts the leading facts as to the strata traversed in clear light. The record is as follows:

1.	Drift		27 feet.
2.	White shale—black at bottom (Cuyahoga and Berea shales)		86 "
3.	Berea grit—with salt-water		27 "
4.	White shale	Ohio shale, 508 feet	65 "
5.	Red shale		30 "
6.	White shale		90 "
7.	Black shale		50 "
8.	White shale		65 "
9.	Black shale		268 "
10.	White shale		60 "
11.	Limestones	Devonian and Upper Silurian, 912 feet	856 "
12.	White shale		26 "
13.	Red shale		20 "
14.	Gray sand		20 "
15.	Red shale, very gritty (Medina)		175 "

16.	Gray shale	60 feet.
17.	Brown shale (Hudson River)	595 "
18.	Black shale	312 "
19.	Trenton limestone, struck at 2,832 feet	32 "
	Depth of well	2,864 "

Salt-water was struck at 920 feet from the surface, or 152 feet below the top of the great limestone series.

The Trenton limestone is reported as very dark. It was entirely unproductive.

Summarized, the section is as follows, viz.:

Ohio shale	508 feet.
Upper limestones	912 "
Lower shales	1,142 "

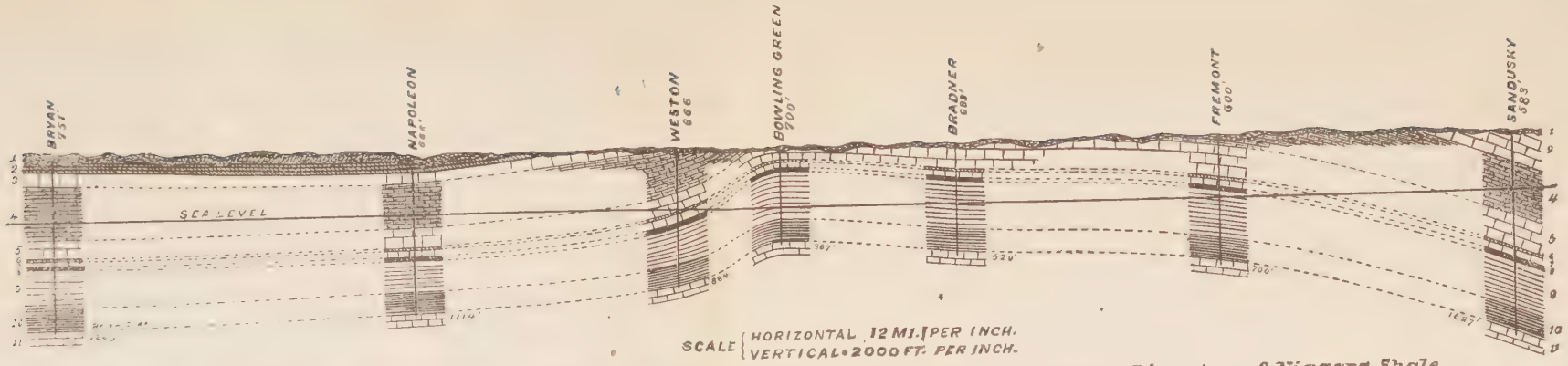
The records now given mark the most eastwardly points to which the Trenton limestone has been traced in wells. These wells have been quite expensive, and any drilled still farther east must be still more so. It is obvious that there is nothing whatever in the records to encourage further explorations of this sort.

The Trenton limestone has been followed far beyond its productive fields in this direction already. Even if it were of the right chemical composition for an oil-rock, it would be quite certain to be buried in a flood of salt-water at these low levels.

The Ironton Well.

The record of the Ironton well (in the Ohio Valley, in Lawrence county), upon which a large expenditure has been made, is of considerable interest, as marking the deepest point at which the Trenton limestone has been reached in the state. It seems probable that this great stratum was struck at the depth of 3,440 feet. The upper portion of the record is very clear and intelligible, but the record of the lower half is less satisfactory. The latter condition results from lack of material and not from any anomalous or unexpected facts. The section appears to be normal throughout.

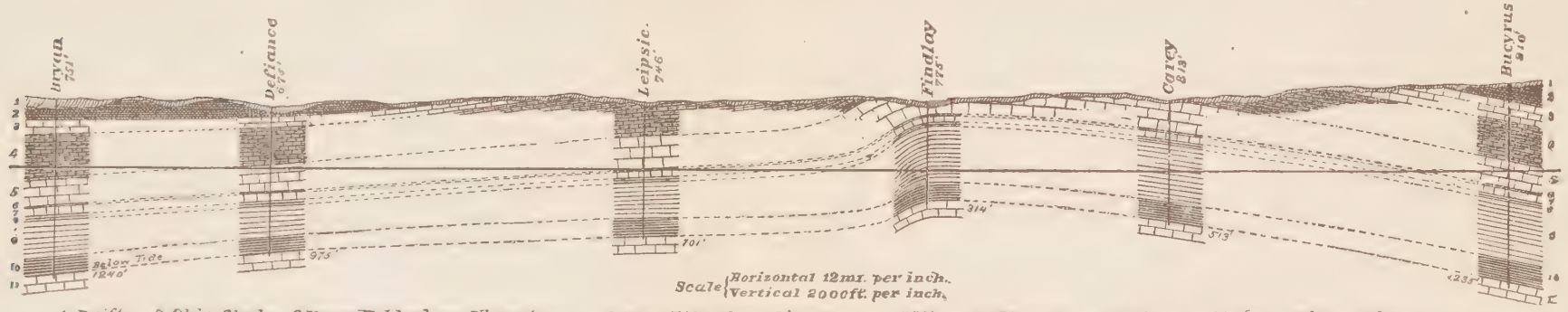
The well was begun in the Conglomerate Coal Measures near the upper Mercer coal level, and 145 feet below the level of the Ferriferous limestone. It is a little less than 550 feet above tide. It was drilled by the Belfont Iron Company, who did not begrudge a large expenditure in making a full test of their own situation with reference to the natural gas supplies that they need so much. The work was begun in 1885, and drilling has been going forward until the summer of 1887, with occasional interruptions from lost tools.



1 Drift. 2 Ohio Black Shale. 3 Upper Helderberg Limestone. 4 Lower Helderberg Limestone. 5 Niagara Limestone 6 Niagara Shale.
7 Clinton Limestone. 8 Medina Shale 9 Hudson River Shale. 10 Utica Shale. 11 Trenton Limestone.

SECTION FROM BRYAN TO SANDUSKY ON A LINE BEARING S.87°E.

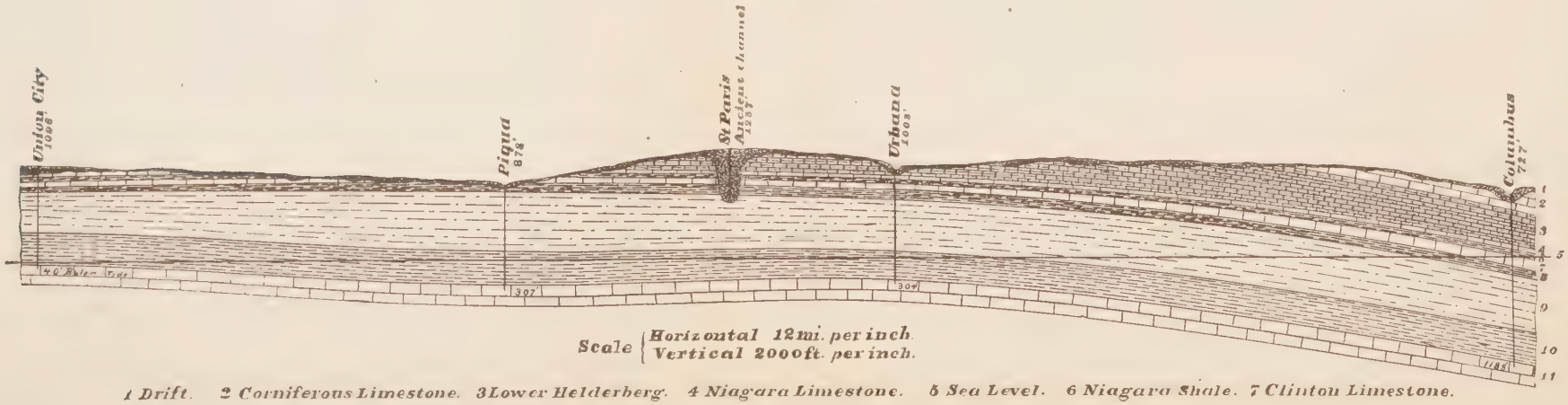
M. R. Campbell, Del.



1 Drift. 2 Ohio Shale. 3 Upper Helderberg Limestone. 4 Lower Helderberg Limestone. 5 Niagara Limestone. 6 Niagara Shale. 7 Clinton Limestone.
8 Medina Shale. 9 Hudson River Shale. 10 Utica Shale. 11 Trenton Limestone.

SECTION FROM BRYAN TO BUCYRUS ON A LINE BEARING S. 60°E.

M. R. Campbell, Del.



1 Drift. 2 Corniferous Limestone. 3 Lower Helderberg. 4 Niagara Limestone. 5 Sea Level. 6 Niagara Shale. 7 Clinton Limestone.
8 Medina Shale. 9 Hudson River Shale. 10 Utica Shale. 11 Trenton Limestone.

SECTION FROM UNION CITY TO COLUMBUS ON A LINE BEARING S.82°E.

M. R. Campbell, Del.

It was not originally directed to the Findlay gas rock, but it was simply drilled to test the ordinary range of rocks of this region. After the Berea grit, which was struck at 1,028 feet, had proved unproductive, the bold plan was formed of drilling the well to the Trenton limestone, this last horizon having become prominent at this time. The record is as follows:

1.	Surface and shales	65 feet.
2.	Sandstone	14 "
3. 4.	Coal, thin, at 79 feet, Fire-clay,	3 "
5.	Blue shale	112 "
6.	Conglomerate stratum	8 "
7.	Blue shale	30 "
8.	Hard white sandstone	10 "
9.	Dark-blue shale	40 "
10.	Sandstone and conglomerate, with many alternations	300 "
11.	Blue shale	30 "
12.	Dark sandstone, fine-grained	30 "
13.	Blue shale, with occasionally thin courses of sandstone	348 "
14.	Black shale	20 "
15.	White sandstone, fine-grained	47 "
16.	Shales	60 "
17.	Sandstone	15 "
18.	Red shale	15 "
19.	Dark shale, mainly black	570 "
20.	Light-blue shale, alternating with black	110 "
21.	Limestone of various shades and grades	584 "
22.	Green shales, interbedded with red rock	336 "
23.	Shales, with limestone bands	695 "
24.	Trenton limestone counted as beginning here	3,440 "
25.	Drilling suspended at	3,600 "

The interpretation of this long record is for the most part obvious and unmistakable.

The Coal Measure Conglomerate and the Logan Conglomerate appear to be blended in one great series, No. 10. In No. 13 the Cuyahoga shale is distinctly shown in normal measure and character. In No. 14 the Berea shale appears in its usual place, overlying the Berea grit, No. 15. In No. 18 we find the red Bedford shale overlying 700 feet of the Ohio shale series. The limestone series that comes next consists of the Waterlime, Niagara and Clinton limestones. Possibly the Corniferous is also present here. The section has just half the thickness that the same strata show in the northern counties of the state. In No. 22 we find the Clinton and Medina, and probably the beginning of the Hudson River shales. The Utica is not distinguished in the drilling. This

part of the well was drilled wet, it having been found impracticable to exclude the deepest lying salt-water. The Trenton limestone, as identified here, agrees in physical characters with the known samples of this rock from other counties of southern Ohio. It is a whitish, flaky limestone, quite silicious in composition, and altogether lacking in the characteristics of an oil or gas-rock. The determination of the Trenton limestone is not confidently made. Black shale was struck below 3,440 feet, and it is quite possible that the stratum counted Trenton is one of the limestone belts enclosed in the Utica shale. These Utica limestones are of the same character as the Trenton. In any case, the Trenton is not far from the bottom of this well. It is nearly 3,000 feet below tide.

The record can be condensed as follows:

Coal Measures	282 feet.
Logan group and Cuyahoga shales	728 "
Berea grit	47 "
Bedford and Ohio shales	770 "
Upper Silurian limestone	584 "
Medina, Hudson River and Utica shales	1,000 to 1,100 "

This is decidedly the deepest well ever drilled in Ohio, and it is a matter of great interest and importance to find as we do that under this deepest cover, the various divisions retain the same characteristics as in their several outcrops.

This well was altogether experimental in its character. When it was decided by the company to push a well down to the Findlay horizon, while there was not a single fact from all the experience then in hand to warrant any expectation of success, neither was there anything to condemn the scheme as sure to result in failure. At the present time the facts have taken the latter complexion, and it can be positively asserted that the Trenton limestone of the Ohio Valley is not a reservoir of petroleum to any such extent as to justify the drilling of deep wells to reach it.

Summary.

The leading facts in a remarkable history have now been stated. Within the last three years a new horizon of petroleum and the gas that originates from it has been brought to light, a horizon which bids fair to be the most prolific single source of gas and oil that has yet been discovered in this country. The discovery comes from an unexpected quarter, viz., from the "black swamp" of old time of northwestern Ohio. Under its broad and level expanses, a few hundred square miles

have been found, distributed through portions of five counties, within which are contained fountains of oil and reservoirs of gas of infinitely more value than any like accumulations hitherto discovered in the state, and fully deserving a place among the most valued repositories of these substances in any quarter of the world.

The good fortune of Findlay and Lima has had a wonderful effect, not only upon the towns directly surrounding them, but upon all adjacent regions, and even upon entire states. Many hundreds of thousands of dollars have been already spent in drilling wells to the Findlay gas-rock throughout Ohio, Indiana, Kentucky and Michigan, and even far beyond the limits of these states. Indiana has developed a gas-field in this horizon, which is in reality a bodily extension of the Ohio field, but which greatly exceeds the latter in area and perhaps also in intrinsic value. Beyond the districts already indicated in Ohio and the one now named in Indiana, however, there has been no adequate return for the large amount of money spent in exploration. In fact, the productive areas make but a small and almost an insignificant fraction of the entire territory that has been tested.

How are these invaluable accumulations, so limited and apparently so capricious in their distribution, to be explained? The answer to this question, so far as it can now be given, is to be found in the preceding pages of this chapter. The facts that are gathered there will be found to make an important contribution to our knowledge of the modes of accumulation of oil and gas. There is a simplicity of structure in the new field that is not paralleled in any of the productive areas hitherto reported upon. The conditions of accumulation are so obvious that he who runs may read them. For missing the true interpretation, there would scarcely be excuse.

The leading facts pertaining to the field can be summarized as follows:

1. In fourteen of the northwestern counties of Ohio (and like conditions prevail in contiguous territory in Indiana), the upper beds of the Trenton limestone, which lie from 1,000 to 2,000 feet below the surface, have a chemical composition different from that which generally characterizes this great stratum. They are here found as dolomite or magnesian limestone instead of being, as usual, true carbonate of lime. Their percentage of lime, in other words, ranges between 50 and 60 per cent. instead of between 80 and 90 per cent., as in the formation at large. These dolomites of northwestern Ohio are mainly quite free from silicious impurities. The dolomitic composition seems to have resulted from an alteration of a true limestone. At least the occasional masses of true limestones charged with fossils, that are found on the

horizon of and surrounded by the dolomite, are best explained on this supposition. In the change which has been undergone, the fossils which the original limestones contained appear to have been for the most part discharged or rendered obscure, as is usual in this metamorphosis. The crystalline character of the dolomite is often very marked, and there results from it a peculiarly open or porous structure. Its storage capacity is much greater than that of ordinary oil sandstones and conglomerates, so far at least as pores visible to the unaided eye are concerned. The change usually extends for ten to thirty feet below the surface of the formation. In some cases, however, sheets of porous dolomite are found as low as fifty feet and very rarely as low as 100 feet below the surface.

The area occupied by this dolomitic phase of the Trenton limestone in Ohio has already been indicated. The eastern and the southern boundaries pass through Lucas, Wood, Hancock, Allen, Auglaize and Mercer counties. It is possible that the line crosses some parts of Ottawa, Wyandot and Hardin counties.

There is good reason to believe that this phase extends far to the northward and westward, outside of the state limits to which it has here been traced. We know that the Trenton limestone is a dolomite when it pitches rapidly down from the northern boundary of Ohio to make the low-lying floor of the Michigan coal basin, and we also know that it is a dolomite when it rises from under that coal basin as a surface rock of the northern peninsula. In like manner, it is a dolomite when it leaves the western boundary of the state under deep cover, and it is a dolomite when it reaches the surface once more in the Galena district of Illinois and Wisconsin.

South of the line laid down in Ohio, there has not thus far been found a trace of the porous dolomite on which the oil of Lima and the gas of Findlay depend. The change is seen to be taking place in Shelby and Logan counties, but beyond them the Trenton limestone is invariably found with a percentage of more than 75 per cent. of carbonate of lime, and rarely with less than 10 per cent. of silicious impurities. It is this last element, with but little doubt, that has resisted the dolomitization of the stratum throughout the southwestern quarter of the state and in all contiguous territory.

To the eastward of the line laid down in northern Ohio, a less definite boundary is to be looked for. It is quite probable that small areas of porous dolomite will be found beyond the line here recognized as the termination of the Findlay phase of the Trenton limestone. More chemical work is needed in this direction, but thus far there are no exceptions known to the statements made above.

Within the limits named, the limestone of course has a considerable variety of grain and texture, but all of the analyses obtained show the stratum to be in the main a dolomite. As already stated, there are occasional patches or islands of true limestone in this sea of dolomite.

2. A porous rock, buried 1,000 to 2,000 feet below the surface of northwestern Ohio, will not be found empty. Nature abhors a vacuum. With what will its pores be filled? Mainly with salt-water of peculiar composition, possibly representing the brine of the ancient seas in which the limestone was laid down. Ninety-nine hundredths, or perhaps nine hundred and ninety-nine-thousandths of the limestone will be thus occupied. The remaining hundredth or thousandth will be filled with the petroleum and gas which have, in the long course of the ages that have passed, been gathered from a wide and general distribution through the water into certain favored portions of the great limestone sheet.

3. This salt-water will be held under artesian pressure. The porous limestone containing it rises to day in Michigan and Illinois, communicating there with surface waters. The pressure of this head of water will be felt through every portion of the porous rock, and when the stratum is pierced by the drill in the areas that are thus occupied, the salt-water will rise with more or less promptness, depending on the varying degrees of porosity in the rock. The height to which the water will rise will seem to vary in wells, by reason of the different elevations of the locations at which they are drilled, but with reference to sea-level, the water columns will be found to closely agree.

The same artesian pressure accounts for the force with which oil and gas escape when their limited reservoirs in the porous rock are tapped by the drill.

4. The accumulation of oil and gas in the porous rock depends altogether upon the attraction of gravitation. The lighter portions of the contents of the porous rock, viz., oil and gas, are forced by gravitation into the highest levels that are open to them. Everything turns on the relief of the Trenton limestone. The gas and oil are gathered in the arches of the limestone, if such there are. In default of arches, the high-lying terraces are made to serve the same purpose, but the one indispensable element and condition of all accumulation is relief. A uniform and monotonous descent of the strata is fatal to accumulation of oil and gas where everything else is favorable. The sharper the boundaries of the relief, the more efficient does it become. Absolute elevation is not essential; all that is required is a change of level in the porous rock. Each division of the field has its own dead line or

salt-water line. Salt water reigns universal in the Findlay field 500 feet below sea-level, except where some minor local wrinkle may give a small and short-lived accumulation of oil or gas. In the Lima field the salt-water line has risen to 400 feet below tide; in the St. Mary's field to 300 feet below tide, and in the Indiana field to 100 feet below tide. These figures stand in every case for the lower limit of production, with the possible minor exceptions already noted. The rock-pressure of the gas decreases to the westward in proportion to this decreasing head of water-pressure.

The large accumulations are derived from the large terraces. The Findlay terrace, for example, consists of a very flat-lying tract, ten or twelve miles across in an east and west line, from which the connected areas of the Trenton limestone slope on every side, and to which, therefore, they are necessarily tributary. The gas terrace of Indiana is, by far, the largest of these several subdivisions of the field. The minor elevations of Oak Harbor, Tiffin and Bryan, for example, give rise to the local supplies of gas or oil in these districts respectively.

It is certain that all the considerable areas of productive dolomite, that is, of the porous phase of the Trenton limestone lying relatively high enough to accumulate gas and oil, have already been discovered. The map showing the relief of this formation, page 47, sets this fact in clear light. Nor does there seem room for many minor arches of importance. The productive field as now defined can be well enough extended by a few square miles on this side or on that, but these additions can scarcely change its general poportions.

Some scanty production can be obtained outside the dolomitic limits already laid down, but it will be remembered that there is more or less magnesia in the limestone around the borders of the true field, and is quite possible that this production is in proportion to the amount of dolomite in the rock.

The general structure and arrangement of the Trenton limestone in Ohio have been abundantly indicated in the data already given, but they are still further shown on the appended sheet of sections. The sections were prepared two years since, and though the main features are unchanged, some of the representations do not exactly agree with present knowledge.

CHAPTER IV.

THE BEREA GRIT AS A SOURCE OF OIL AND GAS IN OHIO.

By Edward Orton.

I. STRATIGRAPHICAL RELATIONS.

The Berea grit holds as central a place in eastern Ohio with reference to oil and gas production as the Trenton limestone does in western Ohio.

As already described in Chapter I, page 35, it is a clean and sharp sandstone of medium grain in its northern exposures. The layers of the formation are sometimes separated by thin carbonaceous films mainly derived from marine vegetation, but occasionally fragments of carbonized tree growths are found in the same position. There is in the formation a thin conglomerate streak that can be followed steadily through several counties, the pebbles of which are mainly quartz, and which range from one inch in diameter downwards.

The sandstone grows steadily finer as it is followed southward from northern Ohio, and at the same time it becomes more impure, but even in the Ohio Valley it does not lose the character of a grindstone grit.

It ranges in thickness from five to one hundred feet in outcrop. A single section is reported in Lorain county, in which 170 feet of uninterrupted sandstone were found by the drill. Under moderate cover in the Mahoning Valley, nearly as great a measurement is found. Though this horizon is subject to frequent and sudden changes, it seldom fails altogether. Its line of junction with the underlying shale is very uneven and irregular, owing to erosion sustained by the formation immediately preceding the deposition of the sandstone. Channels and holes were worn in the shale into which was dropped the sand of which the Berea grit is composed. The sandstone sometimes descends forty or fifty feet in these channels, in less than 200 feet. This irregularity extends, however only to the bottom of the stratum. The upper surface is approximately even and regular.

From the shore of Lake Erie near Cleveland, its outcrop passes southward and westward with a breadth varying between one and ten

miles through Cuyahoga, Erie, Huron, Richland, Crawford, Morrow, Delaware, Franklin, Pickaway, Ross, Pike, Highland, Adams and Scioto counties to the Ohio Valley. It is almost everywhere distinct and unmistakable, and gives rise to a large number of quarries sm ll and great along the line.

From Cleveland eastward through Geauga and Trumbull counties, the formation has not yet been identified at all points as clearly and distinctly as elsewhere, but it is safe to say that it extends throughout this territory with characteristics but little changed from those found in the localities mentioned.

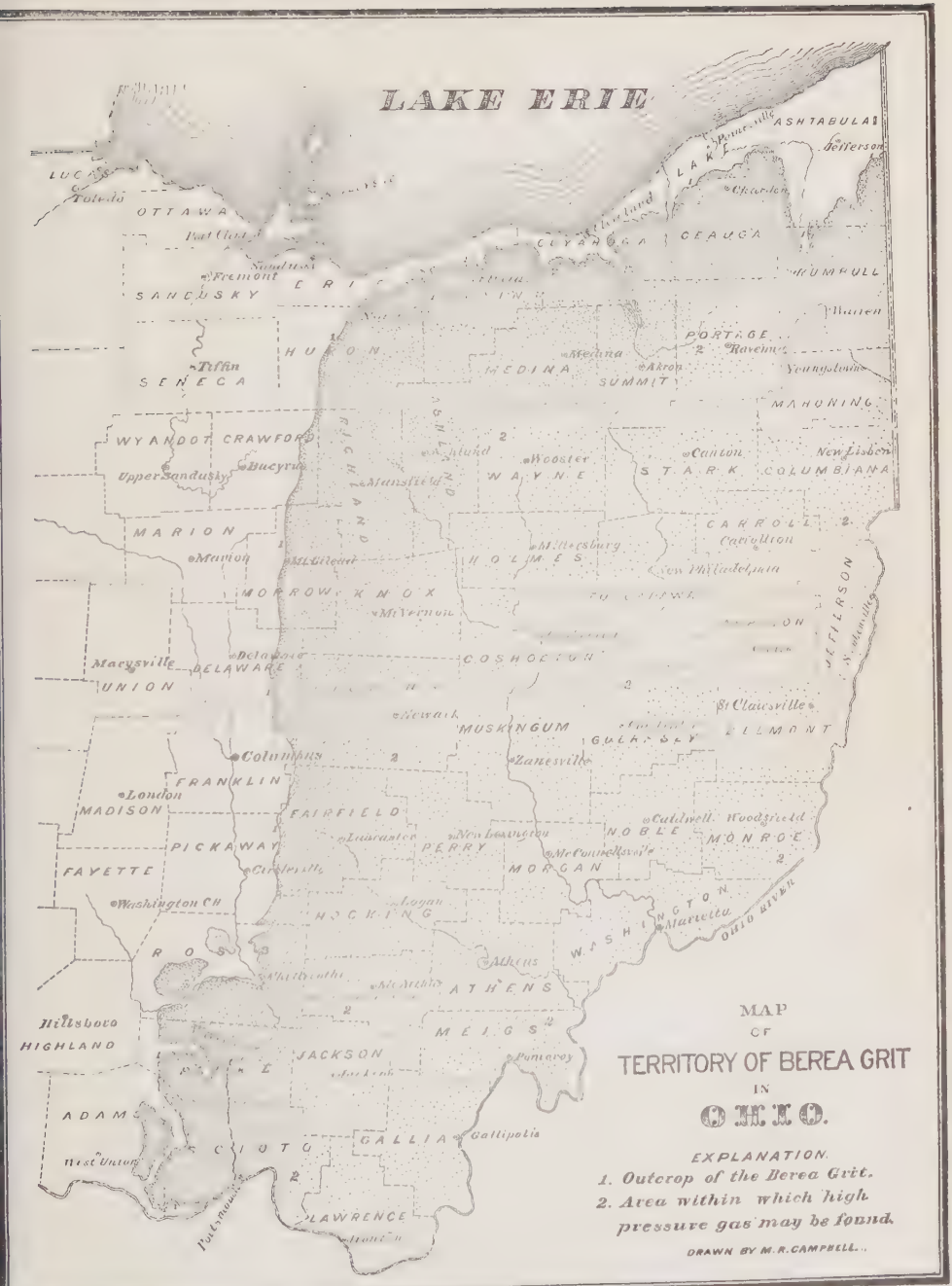
It reaches its highest elevation in the Sunfish Hills of Pike and Highland counties, where it is a little more than 1,300 feet above tide. In Adams, Scioto and Ross counties also, it reaches nearly the same elevation. The western outcrop in Franklin county is about 850 feet above the sea, while at Sunbury, in Delaware county, the western outcrop is about 950 feet above the sea; but the stratum rises again to the northward on the main water-shed of the state. In Richland and Crawford its western outcrop is about 1,125 feet above tide. At the quarries of Brownhelm and Berlin Heights, it has an altitude of a little more than 800 feet, while at Berea its elevation approximates 780 feet. The upper surface of the formation is counted in these measurements.

From the line of outcrop already given the stratum dips prevailingly to the southeast and south, the descent ranging from fifteen to fifty feet per mile. Its lowest levels are found under deep cover in the Ohio Valley between Marietta and Steubenville. The lowest recorded levels are about 800 feet below tide; its vertical range is thus seen to be at least 2,100 feet.

It is geologically due in fifty counties of Ohio, and it is entirely safe to say that it is present in every one, inasmuch as its presence has been proved in all of those in regard to which a question might most easily be raised. In a number of counties where it lies deepest it has been found in hundreds of drill-holes. Its areas above and below the surface, or in other words, in outcrop and under cover, are shown in the accompanying sketch map. A larger map also accompanies this volume.

The stratigraphical relations of the Berea grit in the Ohio scale are such that it is easy to follow it with entire confidence and certainty, not only through all its outcrops from Lake Erie to the Ohio Valley, but under the deepest cover as well.

Although the marks by which it can be recognized have been repeatedly described, they need to be re-stated in this connection. The Berea grit is the first regular sandstone to be reached in ascending the geological column of Ohio, and by the same token the last regular sand


LAKE ERIE
ASHTABULA
Jefferson
LUCAS
Toledo
OTTAWA
Port Clinton
CUYAHOGA
GEAUGA
TRUMBULL
Fremont
SANDUSKY
ERIE
Warren
PORTAGE
Ravenna
HURON
Tiffin
SENECA
MEDINA
Medina
Akron
SUMMIT
Youngstown
MAHONING
WYANDOT
CRAWFORD
Bucyrus
Upper Sandusky
Wooster
WAYNE
Canton
STARK
New Lisbon
COLUMBIANA
MARION
Marion
HOLMES
Millersburg
CARROLL
Carrollton
MORROW
KNOX
Mt Vernon
Macysville
DELAWARE
COSHOCTON
UNION
Newark
MUSKINGUM
St Clairsville
BELMONT
Columbus
Zanesville
FRANKLIN
London
MADISON
FAIRFIELD
Caldwell
Woodsfield
NOBLE
MONROE
PICKAWAY
PERRY
MORGAN
FAYETTE
Washington C.H.
HOCKING
Logan
WASHINGTON
Marietta
OHIO RIVER
ROSS
Athens
ATHENS
Hillsboro
HIGHLAND
MEIGS
Pomeroy
JACKSON
ADAMS
SCIOTO
GALLIA
Gallipolis
West Union
LAWRENCE
Ironton
MAP
OF
TERRITORY OF BEREA GRIT
IN
OHIO.
EXPLANATION.
1. Outcrop of the Berea Grit.
2. Area within which high pressure gas may be found.
DRAWN BY M.R.CAMPBELL.

stone found in descending the scale. The Hillsborough sandstone, the Sylvania sandstone, and the Upper Helderberg sandstone, occur in infrequent and irregular deposits, interstratified with the limestones to which they respectively belong, and while they appear in one section, they are wanting in a thousand. The Berea grit, on the other hand, is absolutely continuous, and is always definitely characterized as a sandstone. It overlies the greatest shale formation of the entire state, viz., the Ohio shales, which, taken together, range in thickness from 300 to 2,000 feet. The Bedford shale is blue, or red in color, the latter color being, whenever it occurs, an excellent mark of the formation. The Ohio shale consists of interstratified black and blue or gray bands. This is the series that is found below the Berea grit. The formation is as definitely marked by the strata that cover it. Its immediate roof is the Berea shale, a firm, fine-grained, highly petroliferous black shale, the lower part of which generally carries a pyritous band of a few inches or one or two feet in thickness, and which is excessively hard.

In thickness the Berea shale ranges from ten to fifty feet. Above the Berea shale is found the Cuyahoga shale, light-colored and compact, throughout which occasional courses of sandstone of fine or medium grain are distributed. There is generally an accumulation of the sandstone at or near the base of the formation. It thus frequently happens that there is a sandstone course overlying the Berea shale, as well as the sandstone formation that underlies it. The Cuyahoga shale has a thickness of 150 to 500 feet. The usual figures are about 350 feet. The Cuyahoga and Berea shales, taken together, are second only in importance to the great series of shale deposits that underlie the Berea grit. Above the Cuyahoga, the Logan group is found, which is composed of sandstones, conglomerates and shales, the sandstones and conglomerates being the more characteristic formations.

It is thus seen that the setting of the Berea grit is very effective as far as affording means for recognizing and identifying the stratum are concerned. It lies buried in a composite mass of shales, and in the largest part of the area occupied it is absolutely the only sandstone that belongs in this portion of the scale. There is no stratum that can dispute with it the place in which it occurs. More than this, the roof of the sandstone is black and hard, while the floor is always soft and often red.

In northeastern Ohio the series is somewhat complicated, both in outcrop and under cover, but there are points enough here to afford means for safe identification in most instances.

Along its outcrop, throughout the drift-covered portions of the state,

the Berea grit itself makes the summit of the sections to which it belongs. The soft cover of the Cuyahoga shale has given way under glacial erosion in most instances, leaving the sandstone projecting as a terrace on its western boundary. This state of things has greatly facilitated the working of the sandstone as a quarry rock.

A number of sections taken along one marginal and three radial lines, that is, either on the outcrop of the Berea grit, or that extends from the outcrop towards the interior of its field, will here be introduced in illustration of the statements already made. These sections are mainly derived from the records of the deep wells that have been recently drilled for oil and gas so extensively through the eastern portion of the state. Beginning on the western outcrop of the formation, we find an excellent series of sections available on an approximately north and south line extending from the lake to the Ohio Valley through the counties of Erie, Huron, Richland, Knox, Licking, Fairfield, Vinton, Jackson and Lawrence. This series is indicated on the accompanying map of the Berea grit territory as line A, and the sections are all approximately marginal.

A. (1) At Berlin Heights, in Erie county, there is a largely worked exposure of the Berea grit three or four miles back from the shore of Lake Erie. It constitutes, in fact, the best known head-land of this entire portion of the state. The formation here has a thickness ranging between forty and fifty feet, and it is, in all respects, normal. It is underlain by the Bedford shale, which here displays its characteristic red color. From the Berea grit to the Devonian limestone that crops out a few miles to the westward, the vertical interval in this district is about 600 feet, as has been proved by a number of wells that have recently been drilled. This interval consists, after the red Bedford is passed, of an alternating series of black and blue shales. The Berea grit can be followed southward without difficulty or question entirely through Erie and Huron counties. It forms the surface rock through all this region, and is worked in a large number of local quarries along the line.

(2) At Plymouth, on the south line of Huron county, it goes under the surface, its uppermost beds lying level with the bed of the Huron river. A well recently drilled in this town has furnished the following record, viz.:

Drift	12 feet.
Berea grit	40 "
White soapstone	42 "
Red rock and brown shale (Bedford and top of Ohio shale)	170 "
Black shale alternating with blue	478 "

The thickness of the shales that occupy the interval between the Berea grit and the limestone is here 648 feet, but as will presently be shown, the lowermost 40 feet may possibly be referred to the limestone series. The top of the Berea is about 990 feet above tide at Plymouth, lying as it does on the low arch that forms the west line of northeastern Ohio. In this record, as in similar ones that are to follow, the drillers' terms and divisions will be mainly followed, but they will be interpreted as far as is necessary by the introduction of the geological names of the formations represented. At Shelby, ten miles south, the sandstone has descended to 140 feet below the surface. An excellent section was obtained here from the record of the deep well that was drilled in 1885. The record is as follows:

Drift		58 feet.
White shale (Cuyahoga)		60 "
Black shale (Berea)		23 "
Sandstone (Berea grit)		56 "
White shale 68 ft. / Red shale 30 ft.	(Bedford)	98 "
Light shale		50 "
Black shale		70 "
Light shale		64 "
Black shale		280 "
Light shale		64 "
Limestone (Upper Helderberg)		—
Interval from Berea grit		657 "

The lower section of shale, 64 feet, is quite calcareous, and may be the Olentangy or Hamilton shale of Newberry. In this case, the thickness of the lower shale series will be 593 feet. A like correction, as has been suggested, may be applied to the Plymouth section.

(3) The next section is found at Mansfield, twelve miles to the southeast. The record of the well drilled in 1886, as far as it concerns these points, is as follows:

Surface and sand-rock (Logan group)		140 feet.
Coarse shale, blue, / Fine shale, blue,	(Cuyahoga shale)	360 "
Black shale (Berea shale)		40 "
Sandstone (Berea grit)		15 "
Blue shale 15 ft. / Chocolate shale 35 ft.	(Bedford shale)	50 "
Black shale		5 "
Gray shale		20 "
Dark shale		80 "
Black shale		15 "
Blue shale		70 "
Dark shale		35 "
Dark shale changing frequently in shade		305 "
Blue shale calcareous		60 "
Limestone (Upper Helderberg)		—
Interval between Berea grit and limestone		640 "
low er member of shale column is counted with limestone		580 "

The upper surface of the Berea grit is here 640 feet above tide.

(4) The next section is found in the record of the well drilled in 1884 at Mt. Vernon, Knox county, thirty-seven miles south and a little east of Mansfield. The record of the well is as follows, but recent drilling has shown the lower portion of it unreliable:

Drift		97 feet.
Sand-rock (Logan group)		45 "
White slate 228 ft. / Dark slate 100 ft.	(Cuyahoga and Berea shale)	328 "
Mountain sand (Berea grit)		30 "
Red rock (Bedford)		120 "
Black slate		97 "
White slate		210 "
Black slate and pyrite		23 "
Light slate		97 "
Lighter shale		30 "
Slate and pyrite		130 "
Dark slate		30 "
White slate		70 "
Dark slate		12 "
Sand		60 "
Shale		"
Limestone (Upper Helderberg) at about (corrected)		1,370 "

The sandstone reported 60 feet thick at 1,174 feet, is probably nothing more than a hard phase of the ordinary shale. The interval between the Berea grit and the limestone is here 867 feet, by corrected figures, showing the thickening that took place in this portion of the old basin. This figure is in keeping with all others obtained in this general region. The top of the Berea grit is here 426 feet above tide.

(5) Newark furnishes the next section. Two wells have been drilled here within the last year. The record of the first is as follows:

Drift		235 feet.
Gray shale (Cuyahoga)		270 "
Black shale (Berea)		40 "
Sandstone (Berea grit)		8 "
White shale 3 ft. / Red shale 40 ft.	(Bedford)	43 "

The top of the Berea grit is here about 285 feet above tide. The record of the second well agrees with that already given as far as the former goes, but it has been drilled much deeper, and is to be carried still further down. The Devonian limestone was struck at 1,430 feet or thereabouts, showing the shale series here to be about 900 feet in thickness. This whole section rises to day twenty or thirty miles to the westward, and is, therefore, particularly clear and satisfactory.

(6) The next section is obtained from Lancaster, Fairfield county. A well drilled here in 1886, gives the following record, viz.:

Drift			132 feet.
Soapstone (Cuyahoga and Berea shales)			268 "
White sand (Berea grit)			20 "
Shale			430 "
Black slate			200 "
Limestone (Upper Helderberg) at			1,030 "

The Berea shale is not named in the driller's record, but it is, without doubt, included in the 268 feet described as soapstone, as it is present in characteristic form in all the outcrops of its proper horizon throughout this portion of the state. The interval from the Berea grit to the limestone, is 630 feet. The surface of the Berea grit is here about 450 feet above tide. It is higher than in the last sections, because the outcrop of the formation is bearing to the west of south at this point.

(7) In Hocking county wells have been drilled at various times and at various places within the last few years, all of which show the series to be entirely regular here. The record of a well drilled at Logan in 1885, is as follows:

Drift			28 feet.
Pebble rock	12 ft.		
Gray rock	105 ft.	(Logan group)	117 "
Shale	3 ft.		
Sand rock	12 ft.		
Sandy shale	65 ft.		
Sand rock	33 ft.	(Cuyahoga shale)	405 "
Soapstone	88 ft.		
Sandy shale	72 ft.		
Soda rock	132 ft.		
Black shale (Berea shale)			59 "
Sand rock (Berea grit)			41 "
Red rock (Bedford)			27 "

The Berea grit is here about 100 feet above tide.

At Bloomingville, on the western side of the same county, a number of wells have been drilled. The record of one is as follows:

Light-colored shales, interstratified with sandstone courses (Cuyahoga shale)			445 feet.
Black shale (Berea shale)			39 "
Oil and salt-rock (Berea grit)			35 "
Soapstone	12 ft.		
Red soapstone	81 ft.	(Bedford shale)	109 "
Soapstone	16 ft.		
Black shale			—

The same series is shown in Vinton county, but no detailed record of drilling done there is at hand. The Cuyahoga shale, Berea shale, Berea grit, and Bedford shale, all in their characteristic phases, are as unmistakable here as in the records already reviewed.

(8) A well drilled at Jackson Court-house in Jackson county, in 1886, found the Berea grit at 700 feet below the surface. The series here was normal in every respect.

(9) This line of sections is terminated at Ironton, Lawrence county, in the Ohio Valley. A deep well drilled here in 1885, furnished interesting and valuable information as to the order of the underlying rocks, and the record is entirely in keeping with what we have already obtained in the district to the north. The record is as follows:

Lower coal measures (Conglomerate group)	282	feet.
Cuyahoga shale, Logan group and Berea shale	728	"
Berea grit, probably including upper portion of Bedford	47	"
Bedford shale, red Ohio shale, black and blue, alternately	770	"
Limestone (Lower Helderberg)	—	
Interval between Berea shale and limestone	817	"
Elevation of the surface of the Berea grit below tide, about	460	"

B. A second series of sections taken along the line marked "B" on the map, can be followed southward from Cleveland to Marietta. The Berea grit is exposed in the walls of the Cuyahoga Valley at Bedford and Independence in its most characteristic and valuable form. Sections embracing the Cuyahoga shale, the Berea shale, the Berea grit, the Bedford shale, and the upper portion of the Ohio shale, are available at many points. At Independence, the Berea grit lies quite high in the hills, but it has descended to the level of the valley at Peninsula. The interval between the Berea grit and the underlying limestone in this region is about 1,400 feet, as is shown by the Cleveland Rolling-Mill well and other deep drillings. The sandstone has an elevation of about 800 feet above tide in its most northern exposure.

(1) At Akron, the Berea grit is found at a depth of 260 feet below the surface, and at an elevation of about 940 feet above tide. It is carried upward here by the water-shed axis, as previously noted (page 58). The section in the deep well drilled here in 1885, is as follows:

Drift	50	feet.
Pebbly sandstone (Conglomerate)	40	"
Shale (Cuyahoga and Berea)	170	"
Berea grit	3	"
Shales, light, dark, black, and blue	1,862	"
Limestone	335	"

The black Berea shale is not reported here. It is sometimes missing in this particular portion of the state. The Bedford is not reported as a red shale at this point, but the section is not at all ambiguous. In a number of wells drilled in this general region the facts appear in normal order.

(2) The second station is found at Massillon. Several deep wells have been drilled here within the last year. The section from one of them is as follows:

Drift	145 feet.
Conglomerate	40 "
Blue and light shale (Cuyahoga)	425 "
White sand (Berea grit)	45 "
Blue shale (Bedford)	40 "
Ohio shale, gray, blue and black	1,820 "
Limestone—Devonian.	

The surface of the Berea grit is about 325 feet above tide at this point.

(3) The next section on line B is found at Canal Dover, where a deep well was drilled in 1884. A more careful record was preserved of this well than of any other in this portion of the state. The Berea grit was found with a thickness of twenty-six feet at the depth of 860 feet below the surface and at an elevation of eighty-four feet above the sea. The section is as follows:

Conglomerate coal measures	235 feet.
Logan group, pebble rock	195 "
Cuyahoga shale	420 "
Berea shale, gas-shale	10 "
Berea grit	28 "

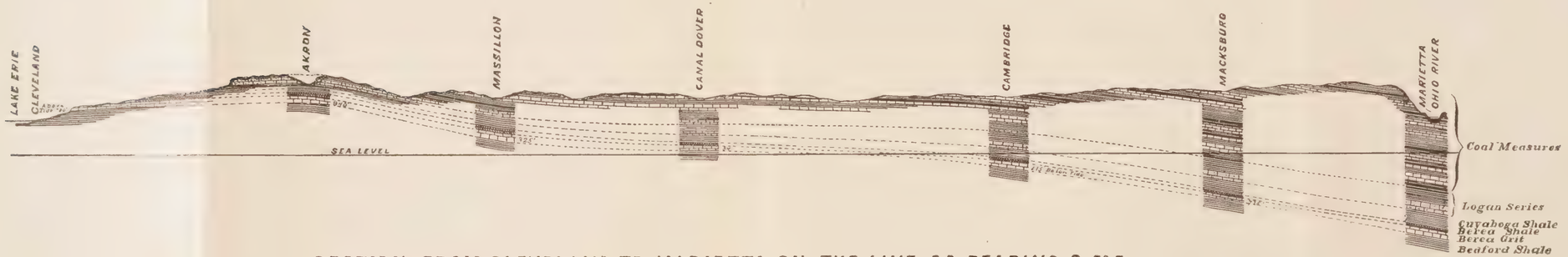
The drill was sunk 1,884 feet below the Berea grit through a constantly changing series of blue, gray and black shales. Drilling was arrested at a depth of 2,760 feet without having reached the bottom of the shale series, but it is probable that the lower limit of the shale series is not far below.

(4) Cambridge, Guernsey county, furnishes the next section. The Berea grit was found here in two wells drilled in 1886 in an unequivocal section. The record of well No. 1, is as follows:

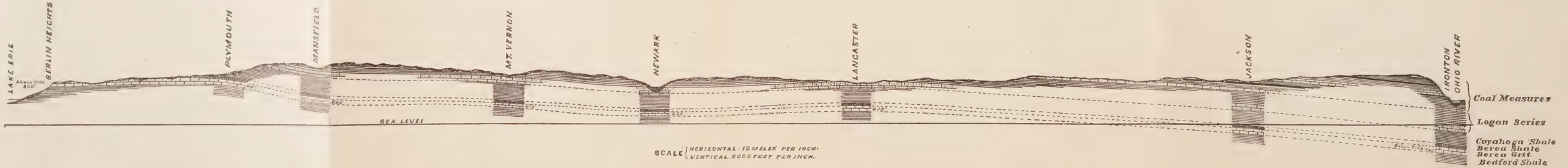
Soil and surface rock			54 feet.
Black sand and shale	25 ft.		
Limestone	10 ft.		
Light shale	136 ft.		
White sand	50 ft.	Lower Coal and Conglomerate Measures	401 "
Shale	65 ft.		
White sand	25 ft.		
Dark shale	90 ft.		
Salt-water sand, with pebbles at base	110 ft.		
Dark shale	4 ft.	Logan group	182 "
Soft sand	68 ft.		
Light shale (Cuyahoga)			340 "
Black shale (Berea)			43 "
White sand (Macksburg sand or Berea grit) with oil-gas and salt-water			65 "
White shale (Bedford)			5 "

SECTIONS TO ACCOMPANY MAP OF THE BEREA GRIT.

SECTION FROM MECCA TO WHEELING ON THE LINE EF BEARING S. 5° E.



SECTION FROM CLEVELAND TO MARIETTA ON THE LINE CD BEARING S. 5° E.



SCALE { HORIZONTAL 12 MILES PER INCH. VERTICAL 2000 FEET PER INCH.

SECTION FROM BERLIN HEIGHTS TO IRONTON ON THE LINE A B BEARING S. 1° W.

M. R. Campbell,

The surface of the Berea grit is about 175 feet below tide at this point.

(5) The next section is taken from the Macksburg oil-field. All the wells drilled in this field, and they are now counted by the hundreds, agree in the following general order, ziz.:

Barren measures, Lower Coal Measures and Conglomerate	800 to	1,200 feet.
Conglomerate sandstone (Logan group, or water sand).....	200 to	300 "
Gray shale (Cuyahoga shale)		300 "
Black shale (Berea shale).....	20 to	50 "
Oil-sand (Berea grit).....	5 to	30 "

In one well the drill was sunk 1,000 feet below the oil-sand, and the record was extended thereby half-way down the column of Ohio shales. No sandstone, aside from "shells," was penetrated in this descent. A like experience was had in a well recently drilled near Marietta. The Bedford and Ohio shales were here penetrated to the depth of 1,260 feet, and only one bed of hard sand was reported in the drilling, and this bed was but five feet thick.

C. A third series of sections can be taken on the eastern border of the state in a nearly north and south direction from Mecca, through Warren, Niles, New Lisbon and East Liverpool to Steubenville. This series is located along or near the line C, on the map of the Berea grit.

(1) At Mecca, Trumbull county, the Berea grit is found forty feet or more in thickness, and, though provided with no cover but the bowlder clay, it is highly petroliferous. It is underlain by many hundred feet of unbroken shale, as has been proved by deep drilling in this vicinity. The surface of the stratum is about 925 feet above tide.

The famous Warren flag-stone lies about sixty feet above the bottom of the Cuyahoga shale. The Berea shale seems to be reduced in this region to a thickness of about eight or ten feet. It is, however, well characterized by the Discina and Lingula which belong to the horizon. In many places it is almost entirely composed of these shells.

(2) At Niles, and also at Youngstown, the Berea grit has been repeatedly struck in wells drilled for oil, gas or water. It lies about 200 feet below the valley here, or about 650 feet above tide, and apparently has the very considerable thickness of 150 feet.

Deep wells at Youngstown have demonstrated that the great shale formation that underlies it has has a very great thickness here. In one recent drilling, 1,400 feet were penetrated without reaching any change of rock. A well drilled at the Rolling-Mill, by Wick Brothers a number of years since, was sunk 2,480 feet without reaching the end of

the shale formation. The drill rested in black shale at the bottom of the hole.

(3) Numerous wells drilled at New Lisbon show a similar state of facts. The driller's record of one drilled in the fall of 1886 is as follows:

Surface	10	feet.
Fire-clay	2	"
Gray sand-rock	28	"
Black shale	35	"
Fire-clay	20	"
White sand-rock	35	"
Fire-clay	10	"
Black slate	15	"
White sand-rock	65	"
Fire-clay	11	"
Black slate	10	"
White sand-rock	70	"
Gray shale and slate	245	"
White sand-rock	54	"
Blue sand-rock	15	"
Black slate and shale	957	"

The last element is the Ohio shale, re-enforced by the Bedford at the summit of the series. The white and blue sand-rock directly above are the Berea grit, here yielding quite a flow of gas and also salt-water. The Cuyahoga and Berea shales are included in the 245 feet next above, while the Logan or salt-water sand is found in the seventy feet of white sand of the record. The level of the upper surface of the Berea grit is about 323 feet above tide at this point.

(4) The wells of East Liverpool and vicinity furnish the next section. The number of these wells is large, and their records all agree as to the essential features of the section. The record of a well drilled in 1885 at Dry Run, a few miles above Liverpool, will indicate the usual order of facts. It is as follows:

Soil		13	feet.
Glass rock		84	"
Mud rock		100	"
Gray shale and soapstone		370	"
Black shale		50	"
Pepper and salt rock.....10 or 15 feet. Gas-rock proper, white..... 20 " Gas-rock, blue..... 20 "	Berea grit.....	50	"

The shale below the Berea grit has been deeply and thoroughly explored here also by the drill, but with not quite the same negative results as reported at the last station, so far as sandstones are concerned. One well was carried 2,500 feet below the Berea grit without exhausting the shale formation, and two or three sandstones were re-

ported in the column. The level of the Berea grit at East Liverpool is about 240 feet above tide. From East Liverpool to Steubenville there is a much more rapid descent of the strata than has thus far been found. In the interval of twenty-four miles the dip of the basal measures is not less than 800 feet, which throws the Berea grit at Steubenville to 560 feet below tide. The Lower Coal Measures, Conglomerate and Carboniferous limestone formations, make 540 feet in the well record here; the Logan group, 265 feet; and the Cuyahoga shale, including the Berea shale, 365 feet. The Berea grit is often reduced to small dimensions, but it maintains its place with surprising constancy. It appears here as a white sandstone, oil or gas-bearing, from five to fifteen feet in thickness. The shales have been penetrated 1,000 feet below the Berea grit at Steubenville without revealing any sandstone stratum of considerable volume. At Brilliant, ten miles below Steubenville, and especially at Wellsburgh, on the opposite side of the river, a large production of gas has been obtained from the Berea grit within the last few years. The stratum is found in a normal and unmistakable section. Its surface lies 607 feet below tide.

D. A fourth radial line of sections will be traced from Shelby through Mansfield, the Neff gas-wells, Coshocton, Cambridge and Quaker City. It follows a southeast course. A part of these stations have already been described. At Shelby the Berea grit lies 940 feet above tide, and at Mansfield 640 feet. This line of sections is marked D on the map of the Berea grit.

(1) At the Neff gas-wells, which are located in the valley of the Kokosing on the east side of Knox county, near the northeast corner of Coshocton, a valuable series of facts has been obtained from seven wells drilled in the immediate vicinity, within the last twenty years.

The records all agree in their essential features. The wells are begun in the Logan group, or the Waverly conglomerate system, and find the Berea at a depth of about 600 feet. Underneath the Berea grit a chocolate-colored band of the Bedford shale occurs as the most characteristic mark. The Waverly group is considerably thicker in this region than in other parts of the state. The series penetrated appears to be divided in the way indicated below, viz.:

Logan group	150 feet.
Cuyahoga shale	450 "
Berea shale, dark	50 "
Berea grit, oil-sand	10 to 20 "
Bedford shale, chocolate-colored	15 to 20 "

Below the Bedford shale the blue and black beds of the Ohio shale

are found in their usual alternation for many hundreds of feet. The Berea grit in these wells (Nos. 1 and 2) is about 235 feet above tide.

(2) A well drilled 2,108 feet deep in Coshocton, in June, 1886, furnishes the following record:

Drift clays and quicksand	171 feet.
Gray shale	29 "
Coal	1 "
Slate	30 "
Sand	10 "
Gray shale, Logan group and Cuyahoga shale	579 "
Black slate, Berea shale	40 "
White sand, Macksburg sand, Berea grit	20 "
Gray shale, alternating with dark and black	1,220 "

The Berea grit is here found at 861 feet by the record given. By another record, it was found at 840 feet. This shows it to be seventy or ninety feet below the sea. The well was drilled by Macksburg drillers who were entirely familiar with the general section, and who were at no loss in positively identifying all of the main elements with the like elements in their own field.

The section at Cambridge, which is the next station in line D, has been already given. The Berea grit is here 175 feet below tide.

Quaker City lies a little to the north of our line, but the section obtained here can be introduced without violence at this point. A well drilled in 1886 furnished the following section:

Barren Coal Measures, Lower Coal Measures, and Conglomerate Measures	750 feet.
Water sand, Logan group	125 "
Gray shale, Cuyahoga shale	441 "
Black shale, Berea shale	30 "
Macksburgh sand, Berea grit, at a depth of 1,346 feet	6 "

This completes the several lines of sections that were undertaken for the purpose of showing the continuity of the Berea grit throughout eastern Ohio. It is hard to see what better demonstration of this continuity could be asked than such sections furnish. Much additional testimony will, however, be found in the detailed statements of sections that are to follow. In the accompanying map, the areas in which the Berea grit lies above sea-level are distinguished from those in which it lies below, the boundary passing through Columbiana, Carroll, Tuscarawas, Coshocton, Muskingum, Perry, Hocking, Vinton, Jackson and Scioto. The entire area occupied by the formation is not less than 20,000 square miles.

II. PRODUCTION OF OIL AND GAS.

A. Source of the Supply.

The Berea grit is a representative oil-rock. The presumption in regard to it in any portion of the state in which it lies below the surface is that oil, gas, or salt-water, one or two or all, will be found in it in appreciable amount when it is reached by the drill. In a field of a few square miles it has been found to contain so large a stock of oil that its production for a year exceeded 2,500 barrels per day, and at many points a small production has been established from it; in several fields it has been found charged with high-pressure gas, and at very many points with low-pressure gas; in others it has been a productive source of brine for the manufacture of salt, and also of bromine, and generally in connection with more or less vigorous supplies of natural gas.

Its oil is not indigenous. There are but few beds of clearer or cleaner sand in our geological scale than this. It would be absurd to suppose that the great petroleum stocks of the Macksburg field have their origin in ten or twelve feet of clean sand which contain the oil. The source of occurrence of oil at Mecca is also decisive as to this point. The Berea grit is here covered only with bowlder clay, so far as much of the productive territory is concerned. It thus appears that the natural shale cover of the sand was all eroded in distant ages. Before this took place the stratum must have been charged with oil. While lying exposed as a surface rock, oil must have continually oozed from it, as we find oil and gas escaping from certain outcrops now, but when the nearly impervious beds of bowlder clay had once more formed a cover the accumulation of oil was resumed in the rock, and thus the somewhat scanty stocks that have been drawn up for the last twenty-five years have originated.

The source of the oil of the Berea grit is not doubtful or problematical, it is obvious and demonstrable. The oil is derived from the great shale series which underlies the sandstone, and is simply stored in the latter as a reservoir. The shales are an adequate source, and they are directly at hand. They contain free petroleum through their whole extent. Some storage is effected in the shales themselves. The hard bands are often found, as the drill descends through them, to hold some small accumulation of either oil or gas, but the great accumulations pertaining to them are, in all cases, effected by sandstones or conglomerates that are buried in the shales. The Berea grit, being the only regular sandstone contained in the Ohio shales within the limits of the state, becomes, as has been noted, a universal source of these bituminous products.

The conditions for these accumulations, so far as source is concerned, are absolutely univeral throughout the territory occupied by the Berea grit. There is everywhere underlying the Berea grit an abundant source of oil and gas. A second condition, which, like the first, is indispensable to oil accumulation, viz., an impervious cover to the oil-rock, is found wherever the Berea grit has its normal roof, viz., the Berea and Cuyahoga shales, but it has this normal roof wherever it lies deep enough to retain it. This condition also is complied with to a large extent throughout the territory in question. A third requisite for oil and gas accumulation, the Berea grit itself meets. As has been already shown, it constitutes a reservoir for both substances. It cannot, however, be claimed that it meets this requisite as effectively and as constantly as the two series of shales that serve respectively as source and as cover meet the conditions imposed on them. It is, doubtless, too fine-grained and too close in parts of its extent to make a good oil-rock. Its thickness is also, in many instances, too small to afford large storage. But still it is true that so far as can be seen, this condition of a reservoir is also fulfilled on a very large scale in the territory under consideration, and we can, accordingly, declare that the three principal requisites and conditions ordinarily laid down for petroleum accumulation occur throughout a large portion of eastern Ohio.

But, although these conditions are present, the stocks of oil that become valuable to us have not been gathered, except at a very few points. It is obvious, therefore, that there is some other essential requisite for large production. This requisite we find in peculiarities of geological structure. There is a small accumulation in the Berea grit almost everywhere, by virtue of its relation to the shales that respectively support it and make its roof, but the oil and gas-fields that deserve the name seem to be characterized in all instances by departures from the regularity of structure which belongs to eastern Ohio generally. The best example of this abnormal structure comes from the most important field of oil production from the Berea grit, viz., Macksburg.

In the vicinity of Macksburg, north of Marietta, the light southeastward dip of the strata is found to be interrupted, and for nearly a mile a terrace-like structure prevails. This is masked, it is true, by the immense erosion which the country has suffered, and only comes into view when the best-known elements of the exposed section as coal-seams are followed by means of the level. All of the strata ever reached by the drill, as well as all that are above the surface, are equally affected by this structural irregularity.

But this terrace is an oil-field, and has been for twenty years. Oil was first found here in shallow wells, from two hundred to three hun-

dred feet deep in the upper Mahoning sandstone. But adventurous drillers, one after another, struck new sources of oil. A second oil-sand, and a third, were discovered at five hundred and seven hundred feet respectively. Finally the drill was sunk deeper still, until, at 1,300 feet, the Berea grit was found, holding a stock of oil large enough to make the Macksburg field, for the first time, a factor in the general market. It has produced as many as 3,000 barrels per day since then, and is now yielding 2,500 barrels per day. (At the present date, October, 1887, it has shrunk to small proportions.)

But the shallow and the deep productive wells are alike definitely limited to the terrace that has been described. In other words, four oil-sandstones become productive in the same area when the structure is found favorable. That they do not communicate with each other is evident from the fact that the oils which they severally contain differ from each other in gravity, in color, and in chemical constitution.

The depth of the Berea grit below sea-level in the terrace is 735 feet. Of twenty-four wells, occupying four square miles in this field, sixteen reach the Berea between 733 and 737 feet, and six are found by their records to be exactly 735 feet.

On the northwestern margin of the terrace, at elevations of 728, 720, 713, and 704 feet, gas is found, but no oil. After many hundred wells have been drilled on all sides, the terrace which has been revealed by the engineer's level is alone found productive.

The grain of the sandstone is in every way as promising, and its thickness as great, outside of the field as within it; and the sections, both above and a thousand feet below the Berea grit, appear identical in productive and in barren territory alike. It is hard to resist the conclusion that the Macksburg oil-field is dependent upon the structural irregularity here described, the other elements, of course, being presupposed. While the first three conditions of petroleum accumulation are found throughout the entire district occupied by the Berea grit, as has been shown, the last condition, which, like the rest, is a vital and altogether essential one, has been but infrequently complied with in the territory under consideration. In other words, the structure of the formation is mainly normal; the dip is regular and uninterrupted; and the monotony of its descent becomes fatal to the gathering of large stocks of oil and gas within it. In point of fact, there are but very few localities in these 20,000 square miles where any noteworthy value has thus far been obtained from the formation in the line of those coveted supplies, and but a single field of large production. There is ample room for future discovery in this territory, it is true; but it will be seen from the review now to be given that tests have been made in a great

many localities, and at some points in sufficient number to demonstrate that either the character of the rock or its structure is such as to discourage large expectations of valuable returns from it.

The general subject of structure, including folds or flexures, and terraces, has already been briefly treated in Chapter I; and the main facts of irregularity in this respect, so far as they have been discovered in eastern Ohio, are there pointed out. It is only necessary to state here, in review, that eastern Ohio is remarkably free from structural disturbances of all sorts. So large an area of old rocks, formed when the earth had presumably an ampler girth than now, could not have adjusted itself to the changing conditions without developing some low folds or arches. Those marks of disturbance we find mainly on the eastern border of the state; but they are in all cases of moderate proportions and often on so modest a scale that they can be detected only by the careful work of the engineer in districts that contain them.

In treating of the subject now in hand, the production realized from the Berea grit thus far will be taken up first; and in the second place, the explorations which have proved unsuccessful, or which, at least, have not yet resulted in pronounced success, will be described. The Macksburg oil-field is so far in advance of all others in importance that it has been made the subject of a separate chapter. Its general character has been described on a previous page.

B. Productive Oil and Gas Fields.

The Mecca Oil Field.

Beginning in Trumbull county, in northeastern Ohio, we find the Berea grit a productive rock, even where it rises to day. The Mecca oil field has been a well-known center of small production since 1860. This production is still maintained, though on an insignificant and ever-shrinking scale.

The township of Mecca embraces a flat-lying tract, the average elevation of which above the sea is not far from 900 feet. Its surface is made up of drift clays that have a thickness of from five to fifty feet. In the vicinity of West Mecca, the underlying rock is a sandstone which crops out to a small extent in the valley of Musquito Creek, and which can be reached at any point by shafts of a few feet in depth. The early settlers were obliged to sink their wells into this sandstone, and the water obtained often carried globules of dark-colored petroleum that would form a film over the surface. From early times the oil was saved in a small way and used for the same purposes as the Seneca oil of New York. But in 1860, when the interest in the Oil Creek region

of Pennsylvania was at its height, the facts in regard to West Mecca oil became widely known, and a whirlwind of speculative excitement invaded this hitherto quiet neighborhood. Wells were drilled here by the hundred, some say by the thousand; and for a few months the Mecca field was a factor of some importance in the infant industry of petroleum production. The total number of wells drilled is estimated at 2 000 to 2,500 by persons well acquainted with the field. The oil was at once recognized as of very different quality from that of the Pennsylvania field. It was a heavy oil, its gravity being 26 to 28 B. It endured an excellent cold test, and, in a word, was found to be adapted in every respect to the highest uses as a lubricant. Its great value was soon learned, and the price rose for a little while to $50.00 per barrel. Although it soon receded from these extreme figures, it has been from that day to this worth many times more in the market than any other natural oil. What little is produced now finds ready sale at $15.00 per barrel.

The wells do not exceed fifty feet in depth. In early times they were put down by hand, but latterly they have been drilled by portable machines that can be hauled from farm to farm by two or three yoke of cattle. The total expense of drilling is covered by a production of 50 to 60 gallons of oil, and the expense of pumping is reduced in like manner to very low terms, portable steam-pumps being sometimes moved from one well to another a few times a year, and in one case a wind-pump is used for raising the oil.

Estimates of the production of the field vary widely. One conservative estimate makes 5,000 barrels the maximum production for a single year, but other estimates make the amount very much larger than this. Single wells are known to have produced from fifty to seventy barrels a day for several months in succession, and some of these wells are credited with a total production of 3,000 barrels. Wells are seldom pumped for more than three months after they are drilled. After that the oil is removed in a primitive way by the sand-pump, the supply continuing indefinitely, so far as present experience goes.

The territory within which oil has been found in paying quantity can probably all be included in a tract five miles long by three miles wide, but half of the production of the field in its best days was derived from a single farm, and the bulk of the oil at all times has come from a few hundred acres at most. In the early days of this production a little gas was found associated with the oil, but the abundant puncturing of the rock that has gone forward here, long ago exhausted this supply on the West Mecca side. A small amount of gas is still found on the east side of Musquito Creek.

In the spring of 1884 a shaft was sunk on the Cowdery farm, on the west half of Section 4, to the oil horizon, the object being to obtain a larger supply of oil. It was held by the projectors of the enterprise that inasmuch as every well in this immediate territory yielded oil, the shaft would secure a production as much greater than a single well as its area should exceed that of a single well. The wells were usually drilled eight inches in diameter. The shaft was made six by eight feet. It furnished an excellent section of the Berea grit. The rock was struck at a depth of seven feet. The first bed which was found was four feet thick. It consisted of uneven bedded sandstone, and is known as the "bogus rock." It always carries a little oil, and for that matter the lower portions of the bowlder clay are often saturated with oil. Under the "bogus rock" there was found thirty feet of shaly sandstone, blue in color, and with many black streaks of vegetable origin, such as are common in the Berea grit in its northern outcrop. This section is known as "flagstone," and is generally rather close-grained, and somewhat impervious to water. At a depth of forty-three feet the oil-rock, so-called, was reached. It consisted here of two or three beds of false-bedded sandstone, the lower one of which is very loosely cemented. The oil-sand had a total thickness of about nine feet. Water came into the shaft in large quantity at several seams or crevices in these lower beds, and the oil was brought along by it in drops, which found their way to the soft sandstone below, in which they were temporarily stored. When the oil is pumped by a steam-pump this loose sand is often brought with it, and the main trouble that is taken in preparing the oil for use consists in the removal of this sand. When the bottom of the oil-rock was reached at a depth of fifty-three feet, three entries or tunnels were driven at right angles to each other, northeast and west respectively. While the work was going forward several tons of sand were raised every day, and a large amount of water was also pumped. A small quantity of oil was produced in both sand and water, but the result was not such as was expected by the projectors of the enterprise, and the novel scheme of mining for oil by regular entries driven into the oil reservoir was soon abandoned. This, however, was not strictly the first attempt that has been made to mine for oil.

The oil-rock has been already described as full of fresh water. A large volume is always found at the bottom of the oil-sand which the driller calls "Lake Erie." Seams occur, however, in the lower part of the oil-rock that reduce the level of the surface water in the wells. These seams are known as "let-offs." The accumulation of the oil is intimately connected with the movements of the water in the rock. The best production occurs after the spring rains, or after heavy sum-

mer showers. The rain seems to wash the oil from the body of the rock and to bring it into circulation. The oil goes wherever the water does.

The section that was obtained from the shaft, and which has been given above, is not quite a normal one. There is in it a larger measure of the upper or flagstone beds, than is usually found. In most of the West Mecca wells there are only about ten feet of this so-called flagstone; under this, the oil-sand, with a thickness of ten to fifteen feet is found. Under the oil-sand, again, is found the "water sand," which is sometimes as much as seventy to eighty feet thick. The Berea grit in this vicinity is thus seen to have a thickness of a hundred feet, or even more. It is always overlain by a thin but very black fossiliferous bed of the Berea shale. An excellent section is furnished in the banks and the bed of Walnut Creek, within the limits of the village of Cortland, and a half-mile below. At the junction of Walnut and Musquito Creeks, the flag-rock that makes the upper bed of the Berea is found in the bed of the stream. It is covered by eight feet of Berea shale, very black and crowded with its characteristic fossils.

The forty feet immediately above the Berea shale are made up of beds of fine-grained stone separated by thicker beds of shale or soapstone—an alternation of materials which is characteristic of this part of the Cuyahoga shale. Above this division are found quite heavy courses of fine-grained stone, over which twelve feet of dark shale occur. Above the shale is the horizon of the famous Warren flagstone. There are twenty feet found in the present section referable to this horizon, but the quality of the rock at this point is inferior.

This valuable stratum is thus seen to have its place about seventy feet above the surface of the Berea grit. Sections entirely similar to this have been penetrated in a number of wells drilled at and near Cortland for either water or gas.

Four wells have been drilled at Mecca quite deep into the Ohio shale, one of them, the Grover well, to a depth of 1,135 feet.

The series traversed consisted of beds of black shale alternating with blue or gray shale, after the usual fashion. They yielded a little gas and oil at various horizons, according to the traditions, but nothing of great value was found in them, and none of them are productive at the present time. Above the Warren flagstone the Cuyahoga shale continues as soft rock until the conglomerate sandstone is reached upon the high ground.

The Mecca field is unique. It has been an interesting one, but it has had its day. There is not value enough in it to warrant the expenditure that would be required to carefully explore its structure. In fact, it is almost impossible at this time to obtain the data essential to an

explanation. The proper time to acquire such knowledge was when the development of the field was at its height. It is not unreasonable to suppose that other similar fields will be found in this general region.

The Belden or Grafton Oil-Field.

An exhausted field of shallow oil of a type similar to Mecca oil is found at Belden, Lorain county. It is better known as the Grafton field. It was discovered twenty-five years ago, in drilling for salt.

The general section at this point is as follows:

Drift	5 to 15 feet.
Blue soapstone (Lower beds Cuyahoga shale)	70 to 80 "
Dark shale, almost black. Berea shale	10 to 25 "
Oil-sand ~~Berea grit~~	5 to 170 "
Average thickness	50 to 60 "
White clay, or putty streak	2 to 5 "
Red soapstone. Bedford shale	30 to 50 "

There have been drilled here a score or more of these shallow wells. The deepest of them was about 320 feet deep, but all the oil has been obtained from a depth of 120 to 140 feet. The Berea grit when fully expanded furnishes a section as follows:

Blue and flinty rock. Flagstone	30 feet.
White sand-rock	40 "
White and fine sand, "flour rock"	40 "
Dark-blue and coarse rock. Hard at bottom	4 to 5 "

The stratum is largely worked at the Black River quarries in Grafton, three miles to the northward, but at this point its thickness is much reduced. These wells were at one time made to yield, by constant care and attention, 2,000 barrels of oil per year. One of the wells, indeed, produced 145 barrels in the first twenty-four hours. Two others yielded respectively 130 and 90 barrels for their first day: but a good average of the wells in their best production, was from three to five barrels per day. The oil is a lubricating oil, of twenty-five to thirty-two degrees of gravity. It is of good quality, but it is scarcely equal to the Mecca oil. That portion which lies in the surface of the oil-rock is heavier than that which comes from below. The oil-rock also carries quite a strong brine in place of fresh water, as at Mecca. The use of the torpedo has not been found to improve the production of the wells. The pores of the sand-rock seem ample already to carry all the oil that the rock contains.

The field is now practically abandoned. A few barrels of oil can be got out at any time and almost anywhere in this immediate district,

but it costs more than it is worth. The shales underneath the Berea grit at this point are probably about 1,400 feet in thickness. No careful examination has been attempted of the structure of the Belden field. The opportunity for such an examination is now lost, as at Mecca, inasmuch as the production has almost entirely ceased.

The East Liverpool Gas-Field.

Returning to eastern Ohio, we find that East Liverpool in the Ohio Valley, and near the Pennsylvania line, has a gas-field which is much more widely known than the amount of gas produced by it would lead us to expect. It has been made known from the fact that the gas produced here has been utilized as fast as it has been discovered in more or less conspicuous ways. It was first turned to account for salt manufacture, and was afterwards used for both domestic fuel and for the public lighting of the streets, and also in the potteries of the town. East Liverpool, in fact, was among the first, if not the very first, of Ohio towns to make use of gas for domestic and manufacturing purposes. Natural gas was discovered here in 1859–60, during the wide-spread explorations that were going forward in the Ohio Valley at that time. A good account of these early wells is given by Newberry in Geology of Ohio, Vol. III, page 116, but in the type section of the wells that is printed in this account, the Cuyahoga shale is shortened, probably by a clerical error, 100 feet. The shale is 320 feet thick, instead of 220, as given in the section. The Berea grit ranges in this territory from 60 to 120 feet in thickness. The upper portion of it, to the extent of five or six feet, is intermixed with black shale, and the drillings of this bed, from their peculiar appearance, have given rise to the name "pepper and salt rock," by which it is known among the drillers.

The section referred to is as follows:

Valley drift	31 feet.
Sandstone and slate	83 "
Slate and coal	5 "
White sandstone	14 "
Hard blue rock	3 "
Clay shale, with streaks of sandstone, Cuyahoga and Berea shales	321 "
Sandstone in three sections, Berea grit	69 "
Gas and salt-water at several horizons in this stratum.	

The wells are 425 to 450 feet deep, from the lower levels of the valley. The gas-rock is known to be the same as the oil-rock at Smith's Ferry. There are two groups of these wells—one at the mouth of Carpenter's Run on the west side of town, and the other group on the east side. In the first, nineteen wells can be counted in the compass of less

than fifty acres, and six of them on a half-acre, but one-third of the entire nnmber have become extinct. In the second group there have been drilled a dozen wells, half of which are unproductive, and the remainder feeble. The strongest well of the town at present is the Aten well of the Gas Company. Measured in July, 1885, it was found to be capable of producing 33,600 cubic feet per day. Well No. 3, in the same group, was found to be producing at the same time 11,300 cubic feet per day. The latter is a fair average of the wells that the village now relies upon. These wells are maintained in production by perpetual vigilance and care. The chief danger comes from inroads of salt-water which finds its way to them either from the gas-rock or some other source. It must be removed every day, if the flow of gas is to be maintained uninterrupted. In fact, the wells are often pumped twice a day. Not more than two buckets of brine are raised at a pumping, but this small amount must be promptly and regularly drawn, or the well will rapidly deteriorate. The gas-rock is porous and permeable to a high degree, as has been demonstrated by many practical tests, and the neglect of any well tells at once on those that are around it.

If the fifty acres of the Carpenter's Run field could have been kept under intelligent control from the first, they would doubtless have yielded a supply many times larger, so far as utilized gas is concerned, than they have yielded, and many times more enduring. There are no means within our reach for the protection of the public interest in these stores of power from the destructive effects of the ignorance and greed of individuals except monopolies.

Gas was first used for cooking and heating and for street lights in East Liverpool in the summer of 1874. Works had been established here for the manufacture of artificial gas, but they had proved unsuccessful. The plant was bought in at a small fraction of the original cost by a new company, and the principal gas wells were secured by the same company. The gas was at once turned into the mains and used without any pressure except that which comes from the wells themselves. The town pays $600 per annum for all the street lights that it sees fit to use. The lights are never extinguished. The city hall and jail are also heated and lighted with gas. There are fifty or sixty private families also supplied with gas from the wells, for which they pay $2.00 to $2.50 per month for every stove. The gas runs short in severe weather. There seems to be no great encouragement to the drilling of more wells in this immediate neighborhood, inasmuch as many late ventures have proved failures.

Gas was early applied in the potteries of the town on a small scale, and the need of a large amount for this very important line of manufac-

tures has become more and more clearly recognized. Various attempts have been made to secure an adequate stock by drilling wells throughout the neighborhood, and in one or two cases by sinking wells to great depth. The record of the deep Knowles well, as furnished by the driller, Wm. Manor, is as follows: The upper part of the section is well enough represented by the record previously given. From the Berea grit downward, shales and slates prevailed to 964 feet, a red shale being found at 700 feet. From 964 to 1,005 feet, Mr. Manor reports a second sandstone, the counterpart in grain and color, as he describes it, of the Berea grit, and, like it, a gas-rock of decided character. From 1,005 to 1,800 feet, two-thirds of the section consists of black slates, the remainder, of light-colored shale. At 1,800 feet a five-foot sandstone was struck, containing gas and oil. At this point, blue flag or shale, with occasionally softer beds, was reached, and it continued to the bottom of the drilling, namely, 2,954 feet. The well was cased at 320 feet in the Cuyahoga shale, and was dry throughout the whole descent. From this record it appears that the Ohio shale at East Liverpool exceeds 2,400 feet in thickness, and is interrupted by sandstone beds at various horizons. The last-named fact is one of great interest, but should occasion no surprise when the results of the drillings in western Pennsylvania in the same great shale formation are called to mind. These deep sandstones of the East Liverpool section, in all probability, represent some of the various oil-sands of the Pennsylvania scale.

East Liverpool lies, in whole or in part, upon a low fold of the strata which is probably the extension of the Fredericktown anticlinal of Prof. I. C. White. The reality of the fold is made apparent from the fact that the Berea grit descends in both directions from Liverpool. At Dry Run, four miles east, it lies about 100 feet lower than it does at Liverpool. At Wellsville, four miles west, it lies seventy feet below the Liverpool level, as has been demonstrated by the drilling of a number of wells at this point, an account of which will presently be given.

The Berea grit has proved fairly productive at various points in this part of the valley. The wells at New Cumberland on the opposite side of the river and a few miles above, are quite well known from the manufacture of lamp-black that has been successfully carried on here for a number of years. The gas has also been utilized in the burning of fire-brick and for household supply. These wells have the same depth as the wells at Smith's Ferry, and show the same section that is found there. The gas-rock lies 600 feet below the valley at this point. It yields a much more vigorous supply than the East Liverpool wells. The production of the smallest of the eight wells that have been drilled here is counted twice as large as that of the best well at East Liverpool.

Most of them have now been producing gas at least ten years, and they maintain their flow fairly well, though requiring constant attention. A fair supply of gas was also found in a single well drilled at Murray's Mills, almost directly south of East Liverpool.

The section of a well drilled for gas in 1885 at Dry Run, four miles above East Liverpool, has already been given on a previous page and in another connection. The section is a normal one in all respects. The top of the Berea grit is here 688 feet below the Middle Kittanning coal seam, and about 350 feet above tide-water. The Berea grit takes cover rapidly as it is followed to the eastward, and becomes a gas-rock of great energy and value along the anticlinals of Beaver county, Pa. At Wellsville, four miles west of East Liverpool a number of wells have been sunk at different times, and one recently to an extreme depth. None of them are productive. It is much to be regretted that no good account of the deep well last drilled has been preserved. It is reported to have been 3,200 feet deep, and yet it did not reach the bottom of the Ohio shale. This measure implies a total thickness of the formation exceeding 2,600 feet, the largest measure that has yet been reported in Ohio. The Berea grit is found about seventy feet lower than at East Liverpool.

The East Liverpool field can not be counted a promising one from the present developments, and yet it offers possibilities of low-pressure gas of a very useful sort. Some of its wells have been yielding gas without interruption since 1874, and are still maintaining their supply.

Steubenville Gas-Wells.

Steubenville can scarcely be counted in the productive territory of the Berea grit. A large amount of money has been expended by the energetic business men of the town, in courageous and persistent search for the new fuel in the rocks that underlie them, and also throughout their immediate vicinity, but none of these wells have paid for drilling. From many of them, however, a small production was realized, which was turned to account as long as it lasted.

The wells in town find the Berea grit at a depth of about 1,250 feet below the valley level. The record of the second well, drilled by the Jefferson Iron Works near their mill in town, will be given at this point. It was furnished by W. H. Wallace, Esq., President of the company. The record was accompanied with a carefully preserved set of drillings, which has been turned over to the use of the Geological Survey. The record is as follows, viz.:

Drift	75 feet.
Bastard limestone	20 "
Blue clay	12 "
Blue sand	5 "
Fire-clay, place of Shaft coal	39 "
Gray sand	13 "
Blue sand	7½ "
Coal	4 "
Fire-clay	60 "
Shale sand	23 "
White sand	85 "
Black slate	20 "
Shale rock	25 "
Black slate and shale	125 "
Green limestone (Subcarboniferous limestone)	5 "
Limestone (Subcarboniferous limestone)	45 "
Black slate (Logan group)	3 "
White sand (Logan group)	82 "
Shale sand (Logan group)	10 "
Black slate (Logan group)	30 "
White sand (Logan group)	140 "
Black slate—Cuyahoga and Berea shale	280 "
Limestone " "	10 "
Shale, bottom part dark—Cuyahoga and Berea shale	75 "
White sand (Berea grit)	5 "
Black slate (Bedford and Ohio shale)	1,290 "

Gas was found in the five feet of Berea grit at 1,225 feet below the surface, or at 550 feet below the sea-level. The production of gas was light, and, worse than that, it was of short duration. A few months made the limit of its life. From one example the history and fate of all the Steubenville wells can be learned.

Between Steubenville and Moundsville more than fifty wells have been drilled during the last five years in the Ohio Valley. The average cost of these wells is not less than $3,000. The most marked success along the line has been attained at Wellsburg, W. Va., and at Brilliant on the opposite or Ohio side of the river. The facts can be best told in connection with Wellsburg.

The Wellsburg and Brilliant Gas-Field.

The Wellsburg gas-field dates back to December, 1882, when the first or Barclay well, No. 1, was brought in. It yielded a vigorous flow of gas, and awakened great interest and excitement throughout all this portion of the valley. Surface indications of gas at Wellsburg had been noted from the settlement of the country, and the sinking of a test well had been discussed for a long time in this community, but the initiative was at last taken by W. C. Barclay, Esq., a leading citizen of Wellsburg.

The record of this well was kept with great care by Dr. E. E. Worthen, of Wellsburg, to whose intelligent interest in the recent developments of the valley the Survey is greatly indebted. The record is as follows:

Drift, clay, sand and gravel	72 feet.
Blue sandstone	6 "
Black slate	35 "
Fire-clay	22 "
Slate	12 "
Coal, (Steubenville Shaft seam)	4 "
Fire-clay	20 "
Slate	60 "
White sandstone	40 "
Slate and shale	74 "
Sandstone	15 "
Slate and shale	75 "
Sandstone, white, gray and blue	145 "
Coal	6 "
Slate and shale	31 "
White sandstone	140 "
Slate and shale	50 "
White sandstone	50 "
Blue shale (bottom portion black)	400 "
Oil-sand	10 "

The interpretation of this record is in the main obvious. The Berea is seen to have a thickness of ten feet, the Cuyahoga and Berea shales of 400 feet, and the Logan sandstone, or water sand, 240 feet. The Coal Measure Conglomerate appears in the heavy sandstones that are above this level. The lowest coal reported here is anomalous. This element appears in several records. The identifications of rocks, as in all other cases, are mainly those of the driller, and must not be insisted upon in all instances. The section of the well herewith given represents adequately all of the wells that have been drilled in this neighborhood, the series being found very regular throughout this entire portion of the valley. The depth of the wells ranges from 1,275 to 1,300 feet below the valley level.

Gas was struck in drilling this well at many horizons. The first was found in the drift in a bed of gravel at forty-three feet, the second was found at 100 feet, just above a bed of black slate, the third was found at 287 feet in the top of a white sandstone, the fourth was found at 400 feet, the fifth at 535 feet, the sixth at 756 feet, the seventh at 857 feet. The well was cased repeatedly before the salt-water was shut off. The casing finally stood at about 900 feet. As is seen from the record above given, gas was found all the way down, but when the Berea grit was reached, a volume was unlocked that burned with a flame fifty feet long, and the roar of the escaping current could be heard for miles. The

casing of the well was thought to be defective from the fact that more or less salt-water was delivered with the gas from the first. From later developments, it is probable that the salt-water came at least in part with the gas from the Berea grit. The great flood of February, 1883, found access to the well and drowned it. It never recovered its vitality after this interruption. Its flow was measured in July, 1885, and the daily product of gas was found to be 30,628 feet.

The Rocky Point well that was drilled in April, 1883, proved to be a geyser. The gas periodically gathered force enough to throw out the salt-water that entered the well with it, and from which it was impossible to separate it. This well was of no value.

The Spaulding well, No. 1, was completed in May, 1883. It showed a good pressure to begin with, but soon ran down to insignificant proportions. The cause of its decline was the influx of salt-water, which, as in other instances, entered from the sand-rock or Berea grit.

The Barclay well, No. 2, was drilled by the side of the Pioneer well, to recover, if possible, the gas lost in the former by the flood of 1883. It proved a successful well in every respect. It was finished in April, 1883. It was measured in July, 1885, and was then producing 469,000 cubic feet per day. These wells were all located below the town near the mouth of Buffalo Creek.

The noted Dalzell well followed soon after. It was the first of the new group of wells located above the town in and at the mouth of Skull Hollow. It proved to be by far the most vigorous of the entire series thus far found. No measurements were taken by which its production can be determined; but according to all accounts it must have yielded several million cubic feet of gas per day. It burned from the well head unobstructed for a number of months.

The gas was utilized in every way which the business of the town would allow during 1884, viz., in a paper-mill, in glass works, in a brick kiln, and chiefly in domestic use. But although the supply of gas was far in advance of all demands, the work of drilling wells still went on, an immense volume of gas continuing to go to waste. In May, 1884, parties from out of town secured a location on a village lot two or three hundred feet from the two Barclay wells already described and proceeded to drill, without any provision whatever for the use of the gas when found. They struck a vigorous flow, as was to be expected from the locality in which they drilled, and the gas blazed into the air without restraint or care for at least fifteen months, to the time when this record was made. The flow of the well was measured in July, 1885, and was found to be 460,800 cubic feet per day. For the fifteen months in which it had been burning, it can safely be counted 500,000 cubic feet per day. The total

production during this time cannot, therefore, be less than 225,000,000 cubic feet. At the low estimate of eight cents per thousand cubic feet, this wanton waste of power makes an aggregate of $18,000 in value. Fourteen wells had been drilled in the summer of 1885; a number have since been added.

It will, perhaps, have been noticed that in giving this account of the field, the past tense has been constantly used. This use is determined by the facts. By the end of 1885, Wellsburg gas was substantially exhausted. The main supply at this time was derived from a single well just outside of the town. Gas has since been piped in from more distant fields. Salt-water had followed up and overrun the wells, one after another, dampening and finally extinguishing their flames. The history is a significant one, and should bring warning to the towns that are following the same line of policy that has here been described. The gas wantonly wasted from the single well above named would have prolonged the Wellsburg supply for months and even years.

The gas-wells of Brilliant, opposite Wellsburg, ran a much shorter course than even the wells just described, and there is nothing whatever to show, at the present time, for the great expenditure that has been made in this interest throughout this entire region.

The district in which these gas-wells have been found, between Steubenville and Wellsville, including both places, is undoubtedly affected by the passage across it of one of the anticlinals that traverse all of western Pennsylvania. The strata, that had been found dipping rapidly to the southward from East Liverpool to Steubenville, are arrested in their descent, and a rate of fall of thirty to forty feet per mile is instantly exchanged for an average descent of seven or eight feet to the mile; and this descent is so distributed that the rocks lie almost absolutely level for considerable areas. The main development of the Wellsburg axis is to be found to the northeastward in Pennsylvania. It seems quite probable that the vigorous wells of the Raccoon district of Beaver county lie on the true summit of this Wellsburg anticlinal.

The Neff Gas Wells.

The most thorough search for petroleum in Central Ohio during the oil excitement of 1865 to 1875, was conducted by Peter Neff, Esq., in the eastern portion of Knox county, and in adjacent territory, No single field in the state has ever been explored at as large an expenditure as this, and from a portion of it there has been realized a considerable return. This is an exceptional fact in outlays of this kind. Most of these investments are permanent. The search for oil was practically a fail-

ure, but instead of oil, large volumes of gas were discovered in several wells, and a novel but important use of the gas was for the first established here on this discovery. The wells were the most notable in their production of gas that had recently been found in the state, if indeed they had ever been equaled in this respect, and thus they became widely celebrated. Furthermore, they were made the subjects of special examination and report by the leading geologists of this part of the country, viz., Newberry and Winchell, and they have thus secured a large measure of prominence in the literature of oil and gas. At a later date, when the survey of the state was in progress, an excellent report upon the field was prepared by M. C. Read, Esq. This appears in Volume III, Geology of Ohio (page 340, etc.)

It is not possible to add a great deal to these several sources of information in regard to these wells, but the present chapter on the oil and gas-production of the Berea grit in Ohio would be obviously and inexcusably incomplete without some account of the present status of this well-known field.

The locations and general relations of these wells have been already shown on page 323. It is there seen that the gas-rock on which they all depend is unmistakably the Berea grit. That the stratum is here affected by the structural peculiarities that are elsewhere associated with the production of oil and gas, scarcely admits of a doubt. The approximate measurements of Mr. Read (taken by an aneroid barometer) which appear in his report, seem to support such a view, but careful determinations by the spirit level are necessary to furnish a proper basis for any reliable statement as to arch or terrace here. The topography of the region is quite bold and well-marked, but there is nothing in it that cannot be well enough accounted for through the ordinary agencies of erosion and atmospheric waste. It is, of course, entirely possible that the watersheds of the present drainage systems are low arches or anticlinals, but this must be proved, not assumed. The presumption is against it. The pressure of the newer fields upon the limited resources of the Survey, during the last three years, has rendered it impossible to give to these questions the attention that they well deserve, but it is greatly to be desired that the extensive and reliable data accumulated by Mr. Neff in his prolonged investigations, shall yet be fully utilized by being incorporated into a system of accurate measurements covering the entire field. Whenever this work is done, it is well-nigh certain that the secret of the unusual production of this district will be brought to light, and at the same time a valuable contribution will be made to the general subject of petroleum and gas accumulations.

Drilling leases are held on a large territory by Mr. Neff and his

associates, and the terms of the leases require new wells to be occasionally put down. Within the last seven years two or three have been added to those previously sunk. Eleven have been drilled in all.

A little cluster of wells, picturesquely located at the junction of the Kokosing and Mohican rivers, monopolizes the economic interest of the entire series. Two of the wells were drilled in 1865, and have been producing gas ever since, much of the time under most disadvantageous conditions. Two of them are of more recent date.

It is here that Mr. Neff established the first works, so far as known, for the manufacture of lamp-black from natural gas. The idea was his own, and he worked out with great ingenuity and perseverance, its practical and successful embodiment in a fairly equipped manufactory. The interest is now quite a large one in western Pennsylvania, and the present yield of the pioneer wells makes but an insignificant fraction of the total production, but all the essential steps of the manufacture, as it now exists, were worked out here and at the beginning. Mr. Neff's location was unfavorable on account of the distance from all lines of transportation, but all disadvantages were for a time overcome.

The quality of the lamp-black, furnished by this process, is recognized as of the highest excellence. Nothing, in fact, is left to be desired. For many years the Neff works have supplied stock to Harper & Bros., the New York Tribune, and other equally well-known printing and publishing houses. The product has also been exported in considerable quantities to Germany and England.

The history of the early wells is to be found in Mr. Read's account already referred to. A few facts recently obtained can, however, be profitably added here. These facts chiefly bear on the life of the wells.

Well No. 1 was drilled in 1865. It is the famous "geyser well" of the early literature to which reference has been made. It was counted at the time that the well was brought in as the most remarkable display of gaseous energy that had ever been put on record in the state. Just how it would compare with the great gas wells of our own day, it is impossible to say, but it would probably be found decidedly inferior to our first-class wells in both volume and pressure. It was allowed to stand without being cased for a number of years until its energy was largely spent. It is now producing, as measured in May, 1887, by the anemometer, 65,000 to 70,000 cubic feet of gas per day, the temperature of the gas being at the time of measurement 62° F.

Well No. 2, also drilled in 1865, was left neglected for nine years. It was then tubed and packed and has been in service ever since. It is now producing 164,376 cubic feet of gas, temperature 59° F., per day.

Wells Nos. 9 and 11, drilled since 1880, are producing respectively 71,000 and 104,000 cubic feet per day.

The combined production of the four wells can be counted 400,000 cubic feet per day, the temperature of the gas being 60° F.

The wells require constant care to keep them free from salt-water, which enters from the Berea grit, in company with the gas. The last two wells not only require frequent pumping, but throw more or less salt water constantly. The older wells require the removal of the salt-water every three or four days. The price of the manufactured lamp-black has been reduced from forty cents to twelve cents per pound by the competition introduced. Under these conditions there is no standing ground for small wells.

It remains to add that this somewhat scanty production of gas is the best supply at present furnished by the Berea grit in the state, outside of the Macksburg field and a few points in Washington county. There are some important facts in the history now set forth, touching the duration of the supply. The two leading wells of the series, Nos. 1 and 2, are now twenty-two years old. More than this, both were sadly neglected in their youth. That anything of the original flow should remain after the repressive action of a water column resting upon the gas rock for years without relief, seems surprising. The native energy of the flow is well attested by its return and its continuance in the volumes already measured and reported.

There is good reason to believe, not only that this field is by no means exhausted, but also that there are other possibilities of the same sort yet undiscovered in this portion of the state. At the same time we cannot forget that the present development stands for a large outlay, and that while individual wells may, perhaps, be found to make return for the money expended upon them, the account of the field is very far from being balanced. All would, however, be changed if any one of the county towns in central Ohio should secure such a supply as Mr. Neff has so skillfully found a use for in the isolated valley of the Walhonding.

III. OTHER EXPLORATIONS FOR GAS AND OIL WITHIN THE TERRITORY OF THE BEREA GRIT.

The Berea grit is not the only oil or gas-rock that is to be found within the area where it occurs. The Logan sandstone, and the Conglomerate and Coal Measure sandstones may all, under suitable circumstances, be found petroliferous, and all are so found. But there is not much reliance to be placed on them in this connection, and they are never found pro-

ductive to any considerable degree, unless the Berea grit is also found productive at the same locality. It is strictly true that this formation is the main source of oil and gas wherever it occurs. If, in any particular territory it is found wanting in this respect, we have no reason to expect, according to present knowledge, that such territory will be found to be a source of high-pressure gas, or of large stocks of oil. It is to be particularly noted that there is no known source of large accumulation in any rock that underlies the Berea grit in the districts which it occupies, so far as Ohio is concerned. In the southeastern part of the state, it is true, there is a bare possibility that the oil-sands of western Pennsylvania, which belong, in the geological scale, between the Berea grit and the Devonian limestone, may come in. One or two of the records already given seem to point to the possible presence of sandstones in this interval; but in all other parts of the field the explorations made are sufficient to demonstrate that there is nothing to be looked for below the Berea grit which can serve as an oil or gas reservoir on the large scale. The fact that the Trenton limestone lies below is not lost sight of, but its presence has no economic significance or value in this connection. If it were proved to hold accumulations in its deep descent under the Carboniferous system of the state, it would still be altogether impracticable to attempt to reach and release them there. The drill would be obliged to penetrate 1,000 to 2,500, and perhaps 3,000 feet of Ohio shale, in the first place, underneath which are due at least 1,000 feet of Devonian and Upper Silurian limestones, very fine and hard, and charged with the rankest of salt and sulphur-water. The wells would need to be cased to the bottom of the limestone series, and this, in itself, is enough to show that any such scheme is thoroughly impracticable. But the Trenton limestone is still far below. Intervening between it and the bottom of the Clinton limestone, the last element of the series already named, there are no less than 1,000, and very likely 2,000 feet of Medina, Hudson River and Utica shales, or sandstones. But even if the drill were sent down through this four or five thousand foot interval, there is not the slightest reason, so far as present experience goes, to expect any large accumulation of petroleum when it gets there. There is not a single fact that points to large stocks in the Trenton limestone when it descends to these great depths in the scale. The possibilities of accumulation are freely admitted, but no facts are known that show such possibilities to be realized.

The Berea grit must then, according to present knowledge, be counted the farewell rock in the oil and gas production of eastern Ohio. There is nothing to warrant the expectation of large stocks of oil or high-pressure gas beneath it. In passing it, we leave the hope of such

supplies behind. Low-pressure gas of a very useful and desirable sort is found in the shale series, but that is adapted to home consumption rather than to long transport and large uses.

To these general and positive statements an exception will perhaps be counted by some in the case of the Lancaster gas horizon which is to be presently described.

Much of the drilling that has been done in eastern Ohio within the last two years has been carried forward without the recognition of the facts here presented. A town or company sets out to secure natural gas from the underlying strata. The company is generally glad to learn that there is a chance for success in the Berea grit, and this horizon is watched with care as the work goes forward, but when the drill reaches it and passes it and finds it destitute of value, the question of supply is very seldom counted settled thereby. The test would be considered very unsatisfactory and the company very much lacking in enterprise, if the search were allowed to terminate here. The drill is continued at work, and 1,000 or 2,000 feet are added to the record of failure already made and established by the negative record of the Berea grit. Especially since the petroliferous character of the Trenton limestone in northwestern Ohio has been discovered, many efforts have been made by towns situated within the Berea grit territory to reach the new horizon. Two or three of these efforts have succeeded. But few of the rest have yet come within 1,000 feet of the goal. There is no reason whatever to believe that the Trenton limestone has any value as a source of oil and gas, when it underlies the Berea grit. The last-named formation, in the areas occupied by it, is usually the only available reservoir of oil and gas on the large scale; but if not the only one, at any rate it is always the lowest reservoir. In many instances small supplies of gas have been found in the Berea grit, but because small, they are counted unsatisfactory, and money enough to drill two or three other wells to this horizon, the aggregate product of which might be worth using, is spent in driving through the shales a deep hole to predestined failure in the barren series beneath.

Under the present section, the deep drilling that has been carried forward in all this part of the state which is underlain with the Berea grit will be considered, even though this formation may have been an unnoticed or unimportant element in the records made of the wells. To this list will be added the account of the wells drilled along the margin of the formation with the purpose of reaching the Trenton limestone. For convenience, the records will be taken up by groups of counties.

A. Deep Wells of Erie, Huron, Lorain and Cuyahoga Counties.

Milan.

The deep well at Sandusky, which was begun in the Upper Helderberg limestone, and which, according to the driller's record, found the Trenton at 2,210 feet, has been already described in Chapter III. Another deep well, drilled in the county early in 1885, deserves record here, viz., the Milan well. It was drilled for a citizens' company, by Mr. W. M. Martin, who preserved a careful and intelligent account of the strata passed through, together with samples of the drillings from very many horizons. Both record and samples have been kindly furnished to the Survey by Mr. Martin. The record, as interpreted by the samples, is as follows:

Drift	14	feet.
Black shale, bottom of Ohio shale	156	"
Limestone, brown, blue and gray, Upper Helderberg, Lower Helderberg and Niagara limestones	1,050	"
Niagara shale and Clinton limestone, the latter red in part	110	"
Medina shale, red	227	"
Hudson River shale, blue and gray, with shales and limestone, to..	2,000	"

It thus appears that the entire upper limestone series is here 1,160 feet thick. This agrees well with the Sandusky record, in which the same elements were made 1,170 feet thick from an entirely independent record. The Milan well was early in the field, but the order of facts developed was exactly what would now be expected and predicted. Bitter and salt-water was found low down in the limestone, and it was necessary, on this account, to set the casing deep. The well yielded neither oil nor gas in any notable amount. The deceptive promise of the black shale that makes the surface-rock here, and that gives rise, as usual, to many small gas springs, encouraged the drilling of the well; but the promise was misunderstood when it was referred to gas from the deep-lying rocks.

Birmingham.

An experimental well has been under way for a year or more at Birmingham, Erie county, under the direction of W. K. Vandergrift. It was begun in the Ohio shales and not very far from the level of the Berea grit. The shales afford the usual surface indications of oil and gas, and have thus given rise to great but delusive expectations, ever since the values of oil and gas have been known. The upper part of the record is not now at hand, but after passing through 600 feet, or

thereabouts, of the shale series, the upper limestone series was struck in due order. This series was finished at 1,705 feet, below which the following record is furnished by the driller:

Shells and slate	100	feet.
Red rock	200	"
Shells and slate	200	"
Limestone	30	"
Shells and slate	285	"
Depth of well at time of record	2,520	"

The "shells," so-called, are hard layers of limestone, generally a foot or two thick. A little salt-water was struck at 1,650 feet. The well was cased as 1,052 feet, in a white shale, the place of which cannot be correlated with any known horizon. The well is directed to the Trenton limestone, but it will require a descent of several hundred feet more to reach this barren rock.

Elyria.

At Elyria several wells have been drilled within the last few years, furnishing a section from the Berea grit, in which they are begun, to the Upper Helderberg limestone. The well of Mr. George H. Ely satisfactorily represents all of those wells, except in one particular. There is found here a very unusual and abnormal thickening of the Berea grit. The record of the well is as follows:

Drift	17	feet.
Berea grit	170	"
Bedford and Ohio shale	800	"
Upper Helderberg limestone struck at	987	"

The dip of this last-named stratum from Prout's Station, south of Sandusky, to Elyria, is 957 feet, or thirty-four feet to the mile in a due east direction. There is also a considerable northerly descent in the dip in this part of the state.

As to the great thickness of the Berea grit, as shown in this well-record, it is to be noted that the formation is unusually irregular here. The Bedford shale on which it rests presents a very uneven surface, due to erosion before the grit was deposited. While probably none of the outcrops of the Berea grit in the neighborhood exceeds 100 feet in thickness, there are records of other wells in the county that show an equal measure. In the oil-wells of Belden the range of the sandstone is said to have been from 5 to 170 feet. The 800 feet of shale in the well consists of the same alternation of black and blue bands that have been elsewhere described. Gas was found in the shale at 300 feet, and at many other levels as the drill went down.

When the limestone was struck a heavy flow of the salt and sulphur-water that is characteristic of it was released. It was afterward shut out of the well by plugging, and an unobstructed flow of the shale-gas was thus rendered available. The well supplies fuel for a large residence two-thirds of the year, but falls short of the demand in the severity of the winter. Messrs. Hogan and Nelson have also drilled wells in town to the bottom of the shale, with similar satisfactory results in securing supplies of gas for household use.

The surface rocks are seen to be much disturbed in the quarries around Elyria, and the facts at hand indicate an anticlinal passing through the center of the town in a northwesterly direction. Further explorations may prove the appearances illusory, and the dips may not be continuous.

Wellington

Two wells have recently been drilled at Wellington by a company of public-spirited citizens, in order to prove the capacity of the underlying rocks as a source of gas. The section obtained in the first well is as follows:

Yellow clay	10 feet.		
Blue clay	41 "		
Quicksand	45 "		
Blue clay	6 "	Drift	108 feet.
Gravel	23 "		
Blue clay	3 "		
Dark shale (Berea)			30 feet.
Mud rock (Berea grit)			8 "
Bedford shale, red			96 "
Black shale			145 "
Blue shale			235 "
Shales, alternately black and blue			320 "
Light-blue shale			103 "

The Upper Helderberg limestone was struck at 1,033 feet, or 174 feet below tide. The Berea grit is represented by eight feet only of muddy sandstone. The surface of it is 721 feet below tide. The well was drilled into the limestone twenty feet. Gas was struck at the following depths: 118, 212, 259, 364 and 434 feet. The first vein came from the Berea shale. The last supply was the strongest of all. The production of gas, as measured by the anemometer through the casing on March 12, 1887, was found to be 8,208 feet per day. An ultimate pressure of fifty-two pounds was reported for the well, but when the well is allowed to flow unobstructed for a time, the pressure rises but very slowly for some time thereafter.

Well No. 2 gives the following section: its production is about half that of No. 1.

Blue clay	40 feet.
Quicksand, red	25 "
Gravel	15 "
Blue clay	5 "
Cuyahoga and Berea shale	50 "
Berea grit	30 "

The surface of the Berea grit in this well is 724 feet above tide. The return of this formation to something like its normal volume in the short interval between the two wells will be noted.

A remarkable and instructive experience is derived from this well. Under the forty feet of tough, compact blue clay which makes the surface of the country here, a bed of clean, white lake sand was struck, which proved to be twenty-five feet thick. This sand was found destitute of water, but charged with high-pressure gas. When tapped by the drill, the gas broke out with great violence, first throwing all the water from the well, and when that was gone, sending out a storm of sand. It is computed that more than a ton of sand was thrown out in this way in the course of a few hours. When lighted, the flame blazed more than twenty feet high. In order to go on with the drilling, it was found necessary to case out the gas. The supply must have been derived from the Berea shale, which was also found productive of gas in well No. 1. In this last-named well, the same bed of sharp sand was found, but it was here filled with water. It may be mentioned, in the same connection, that a bed of sand of the same character was recently struck in the well drilled at New London at the same depth, namely, forty feet, and that here it held quite a showing of oil. It is obvious that the drift-beds furnish in this case the conditions for gas and oil accumulation. The blue clay makes an impervious cover, the sharp sand constitutes the reservoir, while an adequate source is found in the Berea shale that lies below. The element of structure also comes distinctly into view in the fact that in the second well the sand-bed lies eleven feet higher than in the first. It is probable that the sand forms a continuous stratum.

Lorain county agrees with other counties thus far described in the Lake Shore tier, in containing beneath its surface vast stocks of heat and light, but like the other portions of the shale-territory, there is no known source of high-pressure gas available within its limits.

An unproductive well has recently been drilled in Oberlin to the Devonian limestone, which was reached at about 700 feet.

New London.

In the spring and summer of 1887, three deep wells were drilled at New London and in its vicinity. The facts pertaining to them were

carefully collected by Mr. C. E. Healy, and were by him kindly furnished to the Survey. For wells that traverse the Ohio shale series these have all proved singularly barren of gas. The record of the first well, which was located in the village, is as follows:

Clay Sand and gravel Gravelly clay	Drift	90	feet.
Shales, bottom of Cuyahoga and Berea shale		75	"
Fine sand 52 feet. Water sand 31 "	Berea grit	83	"
Bedford shale, red in part		107	"
Ohio shale, with many alternations of color		643	"
Devonian limestone struck at		998	"

One unusual fact in this record is the appearance of petroleum in small quantity in drift sands at forty and again at sixty-three feet below the surface. The oil must have found its way through the gravelly clay from the underlying shales. It will be remembered that a remarkable flow of gas was found from a similar bed of sand in the Wellington section, previously reported.

The Berea grit was full of water in this well. Fresh water was struck at a depth of two feet in the stratum, and salt-water at a depth of twenty-five feet. The well was finally cased at 260 feet.

The Ohio shale was dark when first struck, but not black. It grew darker for 100 feet, from which point the usual alternations were met. The color was quite light at 900 feet.

In the other wells there were no especially noteworthy facts. The Cuyahoga shale furnished considerable gas in No. 2, but the Berea grit was again found full of water, which overran the well.

A record so barren as this was not to be expected in this region. At no other point in this general region has so large an expenditure resulted in so meagre returns.

Chicago Junction.

In Huron county two deep wells have been drilled during last year, viz., at Chicago Junction, and at Plymouth. The record of the former is as follows:

Drift	120	feet.
Dark-blue shale	30	"
Black and greenish-blue shales alternating approximately	150	"

Limestone was struck at about 400 feet, and continued 850 feet to 1,250 feet, where drilling was suspended. Salt-water, charged with sulphuretted hydrogen, was struck at three horizons, the last apparently

being at about 900 feet. The limestone changed in color frequently, and made very hard drilling. At 685 feet there were fifteen feet of dark-blue, hard shales. This horizon, it is well to note, as there seems to be a possibility of service in it in the identification of this difficult series. The stratum appears to be that which Winchell has named the Tymochtee shale of Wyandot county, an element of the Lower Helderberg limestone. Quite a flow of gas was found at the summit of the last series, or directly beneath the 400 feet of drift and shales that cover the upper limestone. This would have been a good place at which to stop drilling. There was nothing to encourage a deeper descent. Several other wells might have been sunk to the same horizon for the money that was used in going down through 850 feet of limestone.

The occurrence of gas at the summit of the Upper Helderberg limestone in this well is an interesting fact. The horizon is one in which gas and oil are due. They are found at about this point in the scale in the Canada field, but in Ohio no large accumulation has yet been discovered in connection with the Upper Helderberg limestone, and at but very few points have even the small supplies here noted been found.

Plymouth.

The Plymouth Natural Gas Company was organized in 1886, with fifty-two stockholders. A well was begun in the summer on the east side of the village. The record, which has been carefully kept, and which is well supported by samples of drillings, has been kindly furnished by Solomon Spear, Esq. It is as follows:

Drift	12 feet.
Berea grit	40 "
White soapstone, 40 feet.	
Red shale (Bedford)	... ..
Shales, brown, black and blue, with two sandy streaks, continuing	600 feet.
Limestone was struck at	700 "

At about 200 feet in the limestone, a belt of dark-blue shaly limestone was found, resembling the bed reported in the Chicago Junction well, and referred there provisionally to the Tymochtee shale.

Since this record was made, the Plymouth well has been drilled to the Trenton limestone, which was reached at a depth of 2,900 feet. An account of the completion of the well is contained in Chapter III, page 302.

Newburg.

Most of the Cleveland wells are shale-gas wells, pure and simple, beginning in shale and ending there. These will be treated in the succeeding

chapter, but the remarkable record of the well drilled during the last two years by the Cleveland Rolling Mill Co., at Newburg, will best find place here. This well is one of the deepest yet drilled in the state, and it has required a large expenditure. Its record is in some particulars anomalous, and no completely satisfactory account can yet be given of the whole of the section reported from it, but the publication of the section will make a comparison of it with other records possible, and thus perhaps lead more speedily to the true solution. The well-head is about seventy-five feet below the bottom of the Berea grit, and about 780 feet above tide. The record is appended:

		Total depth.
Drift, sand, clay and gravel	40 feet.—	40 feet.
Shale, changing in color	1,310 "	—1,350 "
Limestone, solid	310 "	—1,660 "
Sand with first salt-water vein	40 "	—1,700 "
Limestone	290 "	—1,990 "
Rock-salt and shale	164 "	—2,154 "
"Shale"	15 "	—2,169 "
Limestone	81 "	—2,250 "
Rock-salt	50 "	—2,300 "
"Shale," blueish	40 "	—2,340 "
"Sand"	20 "	—2,360 "
Shale	18 "	—2,378 "
Limestone	22 "	—2,400 "
Rock-salt	20 "	—2,420 "
"Shale"	10 "	—2,430 "
Limestone	40 "	—2,470 "
Rock-salt	5 "	—2,475 "
"Shale"	8 "	—2,483 "
Limestone	167 "	—2,650 "
"Oil-sand"	8 "	—2,658 "
Limestone	22 "	—2,680 "
Oil-sand	6 "	—2,686 "
Limestone	64 "	—2,750 "

The shale series is here seen to be about 1,400 feet thick, allowance being made for the absent portions of the Bedford shale.

The Upper Helderberg limestone is included in the 300 feet of solid limestone reported directly below the great shale. The forty feet of sand coming next in order, unlike most of such entries in the drillers' record in western Ohio, is the genuine article. It is a sharply crystalline, unworn sand, of which many of the grains are unusually perfect. It matches well in position to the Sylvania sand of Lucas county. This, it will be borne in mind, is no longer to be referred to the Oriskany horizon, but it is buried under 150 or 200 feet of the Lower Helderberg limestone. If this Cleveland sand is not the equivalent of the Sylvania sand, it is obviously a similar deposit. It agrees in crystalline charac-

ter with the other "limestone sands" of the Ohio scale. Bitter water rose in the well from this level to within 150 feet of the top. The next sheet of limestone, reported 290 feet thick, is undoubtedly a continuation of the Lower Helderberg series. The first of four beds of rock-salt interbedded with shale and gypsum comes next in order. The presence of rock-salt in our Ohio series had not been predicted as geologically probable, but it really ought to occasion no surprise. Rock-salt and gypsum, or anhydrite, are very closely associated in origin and occurrence, both being due to seas reduced by evaporation when shut off from the main ocean. Extensive deposits of gypsum are already known in the Lower Helderberg limestone of Erie and Ottawa counties. Numerous beds of it were found in drilling the deep well at Sandusky in 1886, and at Gypsum it has been quarried on a considerable scale for many years. It appears that when this great limestone series was forming the condensation of the sea-water was carried further in the vicinity of Cleveland than to the westward, where only the gypsum beds were laid down. The rock salt, 164 feet in thickness, extending from 1,990 to 2,154, is not a clear and uninterrupted deposit, but it is broken by both shales and limestone. An analysis of this seam gives the following result: (*Lord.*)

Salt	71.24
Sulphuric acid	1.80
Lime	2.75
Magnesia	0.12
Insoluble residue	17.92

The bed of "shale," fifteen feet, reported by the driller, immediately below the rock-salt, proves, on examination, to be anhydrite or sulphate of lime. The forty feet of blueish "shale," reported from 2,300 to 2,340 feet is also anhydrite. The fifty feet of rock-salt directly overlying it has the following constitution: (*Lord.*)

Salt	83.00
Sulphuric acid	.10
Lime	1.68
Magnesia	.15
Insoluble residue	13.05

The limestone, 167 feet thick, that extends from 2,483 to 2,650 feet, is a nearly pure dolomite. Two analyses of the drillings are given, taken respectively from 2,500 and 2,600 feet below the surface. They are as follows: (*Lord.*)

	1	2
Carbonate of lime	49.31	54.92
Carbonate of magnesia	39.32	43.80
Insoluble matter	3.22	.71

The six feet of limestone next below this bed was found to contain oil in small amount, and is, accordingly, reported as an oil-sand by the driller. The analysis of this "oil-sand" is also appended:

Carbonate of lime	55.45
Carbonate of magnesia	42.34
Insoluble matter	.70

So far as chemical composition is concerned these last two limestones agree with the Waterlime and the Niagara limestone in its Guelph division. There are no other limestones in the scale of the state that have such a constitution. For comparison, analyses of the Niagara and the Lower Helderberg limestones at Genoa, Ottawa county, are appended. They are as follows: (*Lord.*)

	1	2
Carbonate of lime	54.64	55.97
Carbonate of magnesia	45.05	44.27
Insoluble matter	.76	.27

The results are seen to be almost identical with those above reported.

The second oil-sand, 2,678 to 2,686 feet, is also a limestone. The first oil found was rank with sulphur, and was christened by the driller "Tennessee oil" on this account. The second was free from sulphurous products, and was therefore called "Pennsylvania oil."

Such an identification as that suggested on the basis of chemical composition would show the series of the Cleveland well to be expanded above any measure found elsewhere. But the amount is, perhaps, not excessive. At Sandusky the entire limestone series was found to be 1,170 feet in thickness, and a series of deposits like that here described would be likely to acquire larger volume. It would seem to mark a subsiding area.

Since the above statements were made, much additional work has been done upon this well, and some of the later facts have thrown more light upon the interpretation of the record.

The drilling was continued through limestones of the same general character as those last reported, to a little more than 3,000 feet. At this point a small vein of gas was discovered. In undertaking to develop it further, the tools became fast at the bottom of the well. All the resources of the driller's art have been exhausted in trying to release them, but without success. To the fifty-five feet of drilling tools, a "whip-stock," employed in the effort to regain the tools, has been added, and there are now sixty-five feet of iron below the depth of 2,985 feet, to which point the well is clear. Salt-water has entered the well at more than a score of horizons. The main casing, of five and five-eighths inches in diameter, was set at 1,860 feet, after repeated efforts to keep the well dry by casing at higher levels. The drilling had advanced but a little way below the point above-named, when a new invasion of salt-water occurred. Smaller casing was then introduced, and this again has been supplemented in like manner.

The gas-vein that comes from the bottom of the well appears to be quite small in volume, but high in pressure. The latter is reported by Mr. Charles Latimer as at present from 400 to 500 pounds per square inch. The volume is also reported by him, as the result of direct measurements, at 14,000 to 16,000 cubic feet per day. A high-pressure is to be expected from the depth at which the gas is found. Indeed, a much greater pressure would be entirely consistent with even a smaller flow of gas.

As to the horizon of the gas, a little light has been obtained. Among the last drillings, red rock, apparently red limestone, was found. The later description applies to the Clinton limestone, and to this only, in this part of the scale so far as known. The occurrence of gas at the horizon of the Clinton limestone and in close connection with its red beds, is now on record at several points in Ohio, and especially at Newark and Lancaster.

In view of these facts, it seems reasonable to conclude that the rock in which the drill now rests in this deep well is the Clinton limestone. If this determination is correct, the series of limestones from the Upper Helderberg downwards to the Medina shale must exceed 1,700 feet in thickness. The greatest depth before found for the same series is in the Sandusky well, where a measurement of 1,150 feet was reported. It would require an addition of 650 feet to bring that record up to the one now under consideration, but it is to be borne in mind that fully half of this difference is covered by the salt and anhydrite of the later

record. There is no great difficulty, therefore, in this construction of the section, and in view of all the facts it seems probable that the limestones, the salt beds and the gypsiferous beds, 1,700 feet in thickness in the Newburg well, belong to the series shown below, and can be distributed among the several elements somewhat as follows, viz.:

Upper Helderberg limestone	100 feet.
Lower Helderberg limestone	500 "
Salina group	800 "
Niagara limestone, Clinton limestone,	300 "

The Salina group in central New York is counted 1,000 feet thick. If this determination is correct, the Trenton limestone lies not less than 1,000 feet below the present bottom of the well.

The Newburg well has necessarily been an expensive one. It is said to have cost the company over $19,000, and this does not include all of the outlay, as the contractor lost a great deal of time as well as money in getting the well down to 2,700 feet, where he was compelled to abandon it. The progress from that point downwards has been very slow and expensive.

There are certain valuable results, however, to be derived from the well. The demonstration of the fact that extensive beds of rock-salt underlie the city of Cleveland is not to be lightly esteemed. The time may come when use will be made of this fact.

The knowledge of the geological series that is to be traversed here by the drill is also valuable, and can be turned to practical account by this entire section of the state. This costly well has helped to emphasize a demonstration which was, however, very well supported without it, that there is no available stock of high-pressure gas for the northeastern counties of Ohio.

The one lesson which the Rolling Mill well would seem to teach is the one last named. That it has not been learned is evident from the fact that a second deep well is going down in Newburgh. The Axeworthy well was begun in 1887, and has been carried already to a depth of over 1,500 feet. It is duplicating in all essential particulars the record of its predecessor.

B. Deep Wells of Summit, Stark, Medina and Wayne Counties.

Several deep wells have been drilled in Summit county within the last few years. The valley of the Cuyahoga has attracted considerable notice from parties prospecting for oil, either from its marked topography which suggests to the untrained observer the idea of uplifts and dis-

turbance of the rock series, or from the numerous surface indications of gas and oil, which occur along the outcrop of the great shale series of the valley. These indications are nothing but the usual leakage of the bituminous shales, and have no significance whatever with reference to deep supplies.

Furthermore, the considerable elevation of part of its surface may also have seemed a recommendation to the driller. Most of the wells drilled in the county belong in the shale gas series, and will be treated in the chapter devoted to that subject. A few well records will be given in this connection.

Coventry.

In 1882 a deep well was drilled in Coventry township by Brewster Bros. An entire section of this well is not at hand, but the upper portion of it, which has the chief interest for us, is as follows:

Drift	27 feet.
Coal (Akron or Sharon seam)	4½ "
Fire-clay	4 "
Conglomerate	178 "
Cuyahoga shale	170 "
Berea grit (struck at 383)	48 "
Bedford and Ohio shales	368 "

Where this record terminates.

The well was drilled for either oil or gas, but it yielded nothing of any value. No mention is made in the record of the Berea shale, and it is probable that this element is wanting in the immediate vicinity. The Berea grit has good thickness and lies unusually high, in fact, upon the pronounced roll which makes the watershed of northern Ohio. Its elevation above tide-water is nearly, if not quite, 900 feet. A vigorous production of gas, under these circumstances, might well have been expected.

Akron.

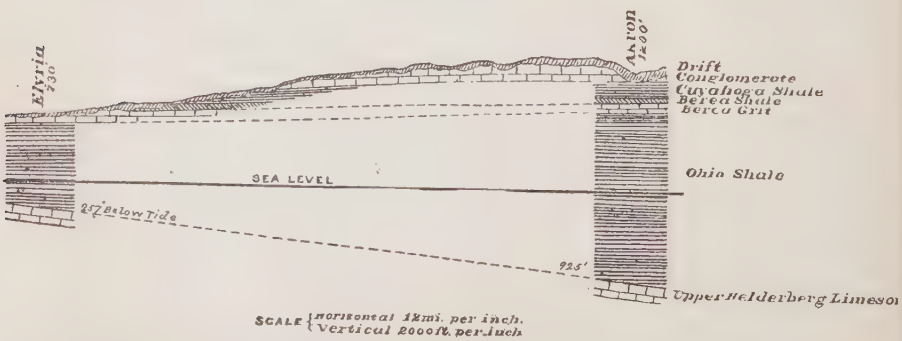
The record of the deep well drilled in the Sixth Ward of Akron by the Akron Sewer-Pipe Works, under the direction of Frank Adams, Esq., has been already used in another connection, and in a generalized way. It will be given here in more detail. The elevation of the well-head above tide is about 1 200 feet.

Drift	50 feet.
Conglomerate sandstone	40 "
Blue shale (Cuyahoga)	170 "
Berea grit	3 "

Light shale, sticky	162 feet.
Darker shale with a little gas	10 "
Blue shale	360 "
Dark shale	400 "
Black shale	30 "
Dark-blue shale	130 "
Black shale	150 "
Brown shale	150 "
Dark and light shale alternating	100 "
Light shale	30 "
Dark shale	120 "
Deep black shale	20 "
Light shale	80 "
"	50 "
Dark shale	70 "
Limestone carrying flint	335 "

An appearance of sand at the bottom of the drillings.

The well is thus seen to be about 2,450 feet deep. From the Berea grit to the limestone the interval is 1,862 feet against 800 feet at Elyria. Possibly a few feet of shaly limestone are found before the limestone was entered in the record of the driller. The surface of the limestone is seen to be 925 feet below tide. The limestone has dipped 700 feet in coming from Elyria to this point. The distance is a little more than thirty-five miles, and the direction southeast. The dip is, therefore, twenty feet to the mile in this direction for the limestone, but not necessarily for other elements of the scale. The dip of the Berea grit is, in fact, reversed, its rate of descent being about six feet to the mile, and the direction of its dip being opposite to that in which the limestone is inclined. It is, of course, the thickening of shales in this interval that brings about these results. The facts are illustrated in the accompanying diagram. There has been much more warping of the crust of the state than its apparently simple stratification and topography would lead us to expect.



. SECTION FROM ELYRIA TO AKRON ON A LINE BEARING S 60°E.

M. F. O.

Clinton.

Several wells drilled near Clinton in the southwestern part of the county in 1882, in search of an imaginary coal vein, showed the same proportions of the several strata that have been reported in the Akron wells. The Cuyahoga shale, the Berea grit and the Bedford and Ohio shales were all found in normal proportions.

Canton.

A well was drilled in Canton, Stark county, by the Canton Steel Company, in 1886, to a depth of 2,220 feet. The record, as furnished to the company by the contractor, has been kindly supplied to the Survey by R. H. Bulley, Esq., Secretary of the company. It is given in substance below. Unfortunately, the record does not give as fully as we could wish a description of the strata penetrated, but contents itself with classification instead for a part of the series. As no samples of the drillings are available in the study of the record, we are left in doubt as to the character of several of the strata passed, and particularly as to the divisions of the great shale formation. The record is as follows:

Drift	17 feet.
Coal	1 "
Slate and sandstone	61 "
Coal, fire-clay, slate and sandstone in thin layers	39 "
Sandstone	49 "
Slate	14 "
Coal, a few inches.	
Fire-clay, slate and thin beds of sandstone	112 "
Conglomerate	140 "
Blue shale (Cuyahoga)	260 "
Sandstone (full of salt-water, Berea grit)	80 "
Shale, dark-red (Bedford)	14 "
"Cleveland shale," light-colored	232 "
"Erie shale"	700 "

Between 1,300 and 1,400 feet, thin strips of sandstone occur. At 1,700 feet the shales changed rapidly to a darker color, and some pieces were black. ("Huron shale" of record.) Thin strips of sandstone, very fine, a few inches in thickness, to the bottom of the well at 2,220 feet. The Berea grit is seen to be, according to this record, eighty feet thick and full of salt-water. Its upper surface is approximately 1,015 feet above tide. The Cuyahoga shale has nearly recovered its normal measure, increasing from 170 feet at Akron to 260 feet here. No mention is made of the Berea shale. A little to the southward this element is found constant and regular, but it may be wanting here. As to what is meant by the "Cleveland" and "Erie" shales of the record, we have no informa-

tion, except that the "Cleveland" is recorded as light-colored. The color of the "Erie" is not suggested in the record, but from the fact that the division below is described as dark colored shale, we may infer that this also is light-colored shale. There is no good reason to doubt that the 1,860 feet of interval, according to the record, between the Berea grit and the bottom of the well, consists of the frequently changing series that is shown in all the carefully kept records of the district, and instead of the three obsolete divisions, Cleveland, Erie, Huron, we should have thirty or forty, if the main changes were all recorded. Neither gas nor oil was found in the well.

A second deep well has been drilled during the present year, viz., 1887, at Canton. It is a matter of regret that its record cannot be added to that already given, but only a single fact is at hand. The upper sheet of limestones appears to have been reached at 3,135 feet. If this is true, a very great thickness of the shale series is indicated.

There is no reason to expect high-pressure gas from the deep rocks underlying this part of the state. If the Berea grit fails, there is nothing more to be looked for so far as can be judged from a wide and varied experience.

Medina.

In Medina county a well was drilled in 1885, near Medina, to the Berea grit and beyond. The section was normal in all respects, and the Berea yielded a small supply of gas for a time.

The record is given below. It was kindly furnished by D. B. Duff & Bro., contractors:

Drift		35 feet.
Sand rock 35 feet. Blue slate 20 " Flint 1½ " Sand-rock 28½ "	(Conglomerate series)	85 "
Blue shale (Cuyahoga shale)		260 "
Black shale (Berea shale)		55 "
Sandstone 5 feet. Gray shale 6 " Sandstone 33 "	(Berea grit)	64 "
Red shale (Bedford shale)		54 "
Black shale 39 feet. Blue shale 512 " Black shale 166 "	(Ohio shale)	917 "

Massillon.

Two wells were drilled in Massillon in 1886 without valuable result, so far as gas and oil are concerned. The first was a test-well put down by a number of citizens on the land of the Russell Manufacturing Company. It was finished early in the year. Its record is as follows:

Drift	145 feet.
Conglomerate rock	40 "
Shales, blue and white (Cuyahoga)	425 "
White sand with gas and salt-water (Berea)	45 "
Blue shale (Bedford)	35 "
Shale (Bedford)	5 "
Blue shale	1,030 "
Dark shale	790 "
Limestone	32 "

The Berea grit, as will be observed, was struck at 610 feet. The well was cased at 695 feet. The well head was about 934 feet above tide. The Berea grit was struck 324 feet above tide. The interval between the Berea grit and the limestone was found to be 1,860 feet. Deducting forty feet for the Bedford shale, we find the Ohio shale to be at this point 1,820 feet thick. A large volume of gas was found in the Berea, but it had no staying quality and in a few hours it was overrun and overpowered by salt-water. The Berea shale is not reported in this well; neither is the Bedford reported as a red shale.

The second Massillon well was drilled by Joseph Corns & Co., at the rolling mill in the northwest quarter of the town. This well found bedded rock at 38 feet, but aside from a difference in this respect it repeated in general terms the record already made by the other well, except that it did not descend below the Berea grit. When this stratum was reached a great volume of salt water rose in the well and put an end to all possibility of service in the way of gas-production. The well was filled and the casing drawn.

There have been other attempts in the way of drilling since the records above given were made, but no very important results have been obtained. The only exception to be made, if any, to this statement, is found in the case of a well reported in July, 1887, by Mr. Otto Uhlendorf. Oil, gas and salt-water were struck at 671 feet, in the Berea grit. The oil showed a specific gravity of 33° B., at a temperature of 86° F. It is a lubricating oil of excellent quality, but there is no reason to expect a paying production from this well.

Massillon would be willing to pay a great price for natural gas, but the experience above recorded does not encourage the belief that it can be found in large enough and lasting enough supply for manufacturing purposes in the strata that underlie this point.

Wooster.

In Wooster, Wayne county, also, a deep well was drilled two or three years since, the record of which, as furnished by Prof. O. N. Stoddard, of Wooster University, is given below. Prof. Stoddard's record is accom-

panied by samples of the drillings, which make the determination of the succession of strata easy and certain. The boundaries of the formations were not, however, in all instances made definite and sharp, and a little latitude must be allowed for the figures on this account.

Altitude of well-head, 1,003 feet above tide.

Drift and Waverly conglomerate or Logan group, approximate...	100 feet.
Cuyahoga and Berea shales, approximate	490 "
Berea grit, sharp, white sand (struck at 590 feet)	65 "
Bedford shale, red (struck at 655 feet) about	145 "
Ohio shale, blue, gray and black	1,200 "

The surface of the Berea grit is 513 feet above tide. The well was finished at 2,000 feet and was unproductive. The Ohio shale consisted of the usual alternating bands of blue and black beds. Wooster appears to be upon the watershed axis, but too low down to borrow any advantage from it.

Wooster was unwilling to consider the question of natural gas supply settled by the negative results of the experiment already described, and accordingly a company known as the Wooster City Mining Association, which had been formed fifteen years before to drill for oil in this vicinity, was revived, and several wells have been drilled by it during 1887. Two of the wells were located at the west of the town and upon territory that was tested in the oil explorations before named. The report of one is given below. The measurements are in excess, but the true order and general proportions of the series are believed to be represented in it:

Drift	28 feet.
Sandstone, with shales (Logan group)	207 "
Shales, with thin beds of sand	215 "
Berea grit	15 "
Bedford shales, red	108 "
Ohio shale, dark-blue	52 "
" " lighter blue	40 "
" " light-blue	60 "
" " darker	15 "
" " alternating, light and dark	165 "
" " darker shale	25 "
" " blue shale	105 "
" " light shale	25 "
" " dark shale	65 "
" " black shale	65 "
" " dark shale	110 "
" " black shale	10 "
" " blue shale	145 "
" " black shale	30 "
" " light-blue shale	90 "
" " gray shale	10 "
" " black shale	5 "

Ohio	shale	dark shale	100 feet.
"	"	black shale	70 "
"	"	light shale	46 "
"	"	blue shale	99 "
"	"	black shale	15 "
Devonian limestone struck at			1,805 "

The interval from the Berea grit to the limestone is 1,237 feet.

A small volume of gas was obtained in one of these wells, but the quantity was inadequate for transportation to any considerable distance. The gas supply of this region is mainly dependent upon the Berea grit, which lies too shallow here to afford very large or lasting wells, but the shales below for a few hundred feet can also be counted a possible source. The town must apparently satisfy itself with supplies of the character here indicated, i. e., with gas of low-pressure and small volume and adapted to household rather than to manufacturing uses. There is nothing to support the belief that high-pressure gas in large and persistent supply is within reach in any of the strata that underlie the town.

C. Deep Wells of Crawford and Richland Counties.

Bucyrus.

The account that follows probably belongs in the preceding chapter, but it was omitted by oversight from its appropriate place.

After an ineffectual effort to reach the Trenton limestone in a well begun in Bucyrus in 1885–6, a considerable amount of money being sunk in the enterprise, a second well was begun in the summer of 1886, and was finished in November of that year, at a depth of 2,264 feet. The well-head is about 910 feet above tide. The record of the first well is as follows:

Drift	20 feet.
Shale, mainly black Ohio shale	140 "
Blue and calcareous shale at	160 "
Limestone from	680 to 840 "

Here the tools became fast, leading to the abandonment of the well after several months had been spent in ineffectual efforts to recover them. A strong vein of salt-water was struck at 780 feet. The second well reports:

Drift	30 feet.
Shale	130 "
Limestone, Devonian and Upper Silurian	816 "
Shales, Medina, Hudson River and Utica	1,170 "

The Trenton was struck at 2,145 feet, and the well was drilled 119 feet into it without any valuable results whatever. The surface of the Trenton was, at this point, 1,235 feet below tide. It agrees almost exactly with the level of the same limestone at Bryan, Williams county. The Trenton limestone was there found 1,240 feet below tide. The limestone series was, however, much thicker at Bryan, and the shales correspondingly thinner. The surface of the Devonian limestone is 750 feet above tide.

In a third well which is being drilled at the present time, more than 200 feet of drift deposits have been encountered.

Crestline.

At Crestline, several attempts have been made during the last three years to reach a source of gas for the needs of the town. The geological horizon of Crestline is at the bottom of the Cuyahoga shale. The black Berea shale is found thirty feet thick at a small distance beneath the surface, being sometimes reached in wells. The Berea grit, in normal thickness and in excellent quality, comes to the surface at Leesville, three miles to the westward, and here also the red Bedford shale is conspicuously shown. The surface of the Berea grit at Leesville is about 1,125 feet above tide. A well, drilled three years since in Crestline, reached a small supply of low-pressure gas at a depth of a few hundred feet in the great shale series, but there was not enough of it for anything more than the feeblest domestic supply. A more ambitious effort in the way of drilling has recently been made during the summer and fall of 1886. A deep well was sunk in this town, which reached the Trenton limestone at a depth of 2,832 feet. It was carried down to a depth of 2,861 feet, where the tools became fast, and all attempts to get them free proved unsuccessful. There is nothing in the experience of northwestern Ohio thus far to give any encouragement to seek the Trenton limestone at these great depths. Published statements assert that $8,000 was spent on this well. The same amount expended on shallow shale-gas wells would certainly supply a great many thousand cubic feet of gas in a day.

The full record of the deep well above referred to, is found on page 303.

Shelby.

In Richland county, deep wells have been drilled at Shelby and Mansfield. The Shelby well was begun in March, 1885. The elevation of the well-head is about 1,076 feet above tide. Its record is as follows:

Drift				58	feet.
Cuyahoga shale, gray, succeeded by Berea shale, black				83	"
Berea grit				56	"
White shale	68	feet.	Bedford shale	98	"
Red shale	30	"			
White shale	95	"			
Black shale	50	"	Ohio shale	657	"
White shale	70	"			
Black shale	280	"			
White shale	64	"			
Upper Helderberg limestone at				854	"

The Ohio shale is seen to be 657 feet in thickness. The driller's division of its elements into white and black shales implies nothing unusual in the character of the formation. The upper surface of the Berea grit is 935 feet above tide. The upper surface of the limestone is 222 feet above tide. From Bucyrus to Shelby the limestone has descended 528 feet, which shows a rate of about twenty-six feet fall to the mile in a northeasterly direction. From Chicago Junction to Shelby, the limestone has descended about 275 feet. Gas was found in the Shelby well in the Berea grit and all through the Ohio shale. At 400 feet, a "blower" of great energy was opened, which blazed and roared with much violence for twenty-four hours, when it exhausted itself. The gas of the well continued to be sufficient for the boiler of the drilling engine for much of the time in which the work was going on. At 1,000 feet, a small vein of gas, rank with sulphuretted hydrogen, was found.

Mansfield.

At Mansfield, a deep well was drilled in the summer of 1886. The well-head is about 1,179 feet above tide. The well was begun in the Logan group, or Waverly conglomerate, and was carried down to the bottom or near the bottom of the Devonian and Upper Silurian limestone series. The well was drilled to 2,005 feet. The record, as kept by the company, and kindly furnished by the officers for the use of the Survey, shows the following interesting series of facts. The record is supplemented by samples of drillings that confirm and establish the interpretations given below:

Sandstone, Logan group				140	feet.
Coarse blue shale	260	feet.	Cuyahoga shale	460	"
Fine blue shale	200	"			
Black shale, Berea shale				40	"
Berea grit				15	"
Blue shale	15	feet.	Bedford shale	50	"
Chocolate-colored shale	35	"			
Black shale	5	"	Ohio shale	590	"
Gray shale	20	"			
Black shale	80	"			
Very black shale	15	"			
Blue shale, with several changes	70	"			
Dark-blue shale	35	"			

Dark shale, frequently interrupted by lighter bands	305 feet.
Calcareous shale, blue and gray	60 "
Limestone struck at	1,200 "

The limestone was drilled into for 800 feet without exhausting the measures. The last element in the shale column could, perhaps, be referred to the limestone series with equal, or with greater propriety. The surface of the Berea grit has an elevation of 530 feet above tide.

The rich and prosperous towns of this portion of the state have been so anxious and earnest in their search for natural gas, that they have refused to abide either by the judgment of geology or the verdict of the drill, but when a deep well has proved a failure, they have moved at once for a new trial. As so often explained on preceding pages of the present chapter, there is no geological probability of high-pressure gas being found under territory occupied by the Berea grit, except in this formation itself. The search for oil or gas in the Trenton limestone underlying these districts is a delusion and a snare.

D. Deep Wells of Knox, Holmes, Coshocton and Tuscarawas Counties.

Mt. Vernon.

A well was drilled three years since at Mt. Vernon to 1,707 feet. The drillers' log, as furnished to the company, has been in turn kindly given to the Survey by General G. H. Jones. The well-head is about 881 feet above tide. The reliability of the record, as to its divisions, is questioned by some who were conversant with the drilling, but its substantial accuracy is attested by its accord with the records of other wells in the region. The lowermost part of the section is most in question.

Gravel 37 feet. Blue mud 7 " Gravel 53 "	Total	97 feet.
Bed-rock, Logan group		45 "
White slate 228 feet. Dark slate 100 "	Cuyahoga and Berea shales..	328 feet.
Mountain sand, Berea grit Carrying soft water.		30 "
Red rock, Bedford shale		120 "
Black slate 97 feet. White slate 210 " Black slate with pyrite 23 " White slate 97 " " 30 " Slate and pyrite 130 " Darker shale and pyrite 30 " White slate 70 " Dark shale 12 " "Sand" 60 " Shale 295 "	Ohio shale reported...	1,174 feet.

The limestone was struck at 1,629 feet, and was drilled into for seventy-eight feet, when the rope broke and the well was abandoned. Salt-water was struck at 500 feet, and the casing was set below it. As usual, a little gas was found escaping from the well, but the supply was of no value.

Mt. Vernon is just about embarking on a more expensive and continuous search for gas than has heretofore been undertaken. The first of three wells to be drilled has already been contracted for. In case of failure in the first, the line is to be extended to the eastward, the hope being that a supply similar to that of the Neff wells on the eastern side of the county can be found in this direction. It is also in contemplation to attempt to reach the Trenton limestone. The Neff wells that are located in this county have been already treated in a separate section, page 339. (December, 1886)

The results of the search referred to in the preceding paragraph can be given in part, The first of these wells was drilled in the spring and summer of 1887 to a depth of 2,600 feet or more. The Berea grit was found twenty feet thick at a depth of 453 feet. The interval from the Berea grit to the Devonian limestone is 887 feet, the latter stratum being reached at 1,340 feet. At 1,960 feet, a strong flow of salt-water was struck, a weaker vein having been passed at 1,518 feet. The main vein, which nearly fills the well from bottom to top, seems likely to have come from the Niagara limestone. The Niagara shale appears to have been reached at 2,125 feet.

A considerable proportion of the well was drilled wet, the tools descending but eight or nine feet a day into the rock through nearly 2,000 feet of salt-water. So far as learned, no production worthy of note has been secured from this well. The Trenton limestone must be at least 3,250 feet below the surface at Mt. Vernon, and is not any more likely to be found an oil-rock here than any other stratum of the scale. It has been found utterly devoid, not only of all production, but of all capability of production for at least 100 miles west of Knox county.

Millersburg.

A test-well was drilled in Millersburg, Holmes county, in 1886, by a local company. The elevation of the well-head is about 892 feet above tide. Soil and surface waste held for thirty-five feet. The rock, where first struck, was found broken and disturbed to some extent. The Cuyahoga shale, when reached, was found normal in all respects. The Berea grit is reported to have been struck at 725 feet, or 167 feet above tide. This is deeper than was expected from comparison of the

records of wells nearest to Millersburg. Drilling was continued through the Ohio shale to a depth of 2,100 feet. The last drillings were black shale. These facts indicate that the shale series here has a thickness exceeding 1,300 feet. It is probable that 1,600 or 1,700 feet would be found if the work were pushed on until the limestone is reached. The record, as furnished by the company, is as follows, but parts of two records seem to appear here. The Drift had no such thickness in the well described above:

Drift		200	feet.
Logan group	Sandstone	25	"
	Shale	15	"
	Sandstone	40	"
Shale, light and dark (Cuyahoga and Berea shales)		445	"
Sandrock (Berea grit)		20	"
Bedford and Ohio shales	Slate, dark	140	"
	Sandstone	10	"
	Slate, light	470	"
	Slate very dark	40	"
	Slate alternatively light and dark	290	"
	Hard rock, sand or lime	5	"
	Slate, light and dark	175	"
	Black slate	25	"
	Slate, light and dark	200	"

A well producing gas and oil from a depth of 900 to 1,000 feet was recently reported on the Netherow farm, four miles from Millersburg. It is probable that the source of production is the Berea grit. If the well were begun on the highlands, the greater depth of the oil-rock could be easily explained.

Coshocton.

At Coshocton, Coshocton county, a deep well was drilled in 1886. The elevation of the well-head is about 771 feet. The record, as kindly furnished by W. H. Parrish, Secretary of the Natural Gas Company, is as follows:

Drift containing much quicksand		171	feet.
Conglomerate Coal Measures	Gray shale	29	"
	Coal	1	"
	Slate	30	"
	Sandstone	10	"
Gray shale (Logan and Cuyahoga shale)		579	"
Black shale (Berea shale)		40	"
Sandstone (Berea grit)		20	"
Shales, black, blue and gray, in frequent alternation (Ohio shale)		1,220	"
The well was finished at		1,280	"

A small amount of oil was found in the Berea grit, associated with salt water. The well had no economic value. It was sunk by veteran drillers from the Macksburg field, who did not fail to recognize the

identity of the section with the lower part of the section in their own wells. The surface of the Berea grit was found ninety feet below sea-level. Between the record of the company and the samples of drillings saved, there is, however, a discrepancy as to the place of the Berea grit to the extent of twenty feet.

Canal Dover.

At Canal Dover, Tuscarawas county, a very deep and thorough test of the underlying rocks as to their petroliferous character was made in 1884. The well, which was drilled by Mr. C. W. Bodey, was the pioneer well, so far as great depths are concerned, of this portion of the state, and its record became, on this account, unusually interesting and instructive. Too much credit cannot well be given Mr. Bodey for the care with which he followed the descent of the drill into these then unknown depths. Samples saved from all the well-marked changes in the drill-hole were turned over to the Survey, and there is thus in hand a perfectly authentic account of the successive strata in central Ohio, to a depth of nearly 3,000 feet. The record of this well is beyond question the best yet made of the series which it represents. Drilling was begun at the level of the Lower Mercer limestone, and at an altitude of about 884 feet above tide. The record can be generalized in the following terms:

Lower Coal Measures	235 feet.
Logan group or Waverly conglomerate	195 "
Cuyahoga shale	419 "
Berea shale, black	11 "
Berea grit	26 "
Bedford and Ohio shales	1,874 "

The drill rested in black shale at a depth of 2,760 feet, where the well was finished. It is not likely that the shale series extends very much further at this point. At Massillon, a few miles to the northward, it was 1,860 feet thick. The Berea grit was reached at a depth of 860 feet, or twenty-four feet above tide. It yielded a little gas and some salt-water. A more detailed account of the shale series is appended, the record being deduced from the samples of drillings already referred to.

The impossibility of dividing a column like this into the three divisions formerly laid down, viz., Cleveland, Erie, Huron, based chiefly on the color of the shales, is obvious.

At 886 to 898 feet, yellowish-blue shale, part of Bedford.
At 1,200 feet, brown, light-brown, or drab shales.
At 1,240 feet, gray shale.
At 1,550 feet, blueish-brown shale.
At 1,600 feet, light-blue shale.
At 1,632 feet, dark-blue shale.
At 1,655 feet, gray shale.
At 1,656 feet, black slate, thirty feet thick.
At 1,710 feet, light-blue shale.
At 1,900 feet, dark-blue shale.
At 1,920 feet, black shale, thirty-five feet thick.
At 1,920 feet, brownish-black shale, thirty-five feet thick.
At 1,965 feet, gray shale.
At 1,975 feet, light-blue shale.
At 2,000 feet, dark-blue shale.
At 2,075 feet, black shale, twenty feet thick.
At 2,105 feet, gray shale, fifteen feet thick.
At 2,120 feet, black shale, ten feet thick.
At 2,200 feet, dark-blue shale, fifteen feet thick.
At 2,300 feet, gray shale.
At 2,365 feet, dark-blue shale.
At 2,431 feet, dark-blue shale.
At 2,475 feet, light-gray shale.
At 2,508 feet, dark-gray shale.
At 2,630 feet, dark-gray shale.
At 2,631 feet, black shale.
At 2,682 feet, dark shale.
At 2,720 feet, banded shale, drab and blue.
At 2,730 feet, black shale.
At 2,760 feet, gray shale, banded with chocolate.

A part of these determinations are based upon large fragments of the shale which are credited to particular depths as above reported. It is possible that some of these pieces may have fallen from upper portions of the well to the bottom, and that the order may thus, to a certain extent, be erroneously given, but no large amount of uncertainty can happen from this source.

E. Deep Wells of Licking, Muskingum and Guernsey Counties.

Newark.

Two attempts to reach a supply of natural gas for Newark, Licking county, have been made by the citizens of the town within the last year, or rather are now being made, as neither of the wells is counted finished, though operations are temporarily suspended on both. The first well was begun by an informal organization of citizens, who started the drill on the banks of the Licking in the western part of the town. The location proved unfortunate, as the drift was found very thick and

hard to penetrate at this point. The elevation of the well-head was about 830 feet above tide. The Berea grit was reached at a depth of 546 feet, or about 254 feet above tide. It proved very thin at this point, but true to its character it yielded a little gas, and with the gas some salt-water was also produced. A little additional gas has also been derived from the underlying shales, which were penetrated to a depth of several hundred feet, but there is nothing thus far in the record of the well to indicate that fuel of any great value is buried under this part of the town. The record of the well is given below:

Drift	236 feet.
Blue shale (Cuyahoga, lower part)	270 "
Black shale (Berea shale)	40 "
Sandstone, containing gas with a little salt-water (Berea grit)	3 "
Bedford and Ohio shales, succeeding for	900 "

This well was drilled with pole tools, and its progress has been slow. It was filled up to the Berea grit recently and a measure of the pressure of the gas yielded by the rock was obtained. The gauge showed a maximum closed pressure of forty-nine pounds, several hours being required to reach this point. The volume of gas was too weak to move the anemometer.

The well was afterwards shot with a charge of rackrock, but no great addition to its flow was secured. What little gas there is shows great persistency. The facts pertaining to this well were kindly supplied by J. W. Blair, Esq.

The second well was begun in October, 1886. It is located near the Everett Glass Works, the fact being recognized that this manufacture is in more urgent need of natural gas for fuel than any other interest of the town. The record of the well is as follows, all of the elements appearing in their normal conditions:

Drift, 165, Cuyahoga shale, Berea shale and Berea grit, 370 feet. The well is cased at 535 feet. The Bedford and Ohio shales are about 900 feet thick, the limestone series being struck at about 1,436 feet. The upper portions of the limestone were dark and highly bituminous. It is possible that these beds should be referred to the shale series. The first light colored limestone reported in the samples occurs between 1,500 and 1,600 feet. A blue shale appears in soft drilling, eighty or more feet thick, at about 2,000 feet. (January, 1887.)

The later facts pertaining to this well deserve a place in the record.

Drilling went forward slowly until the last of February, 1887, when at a depth of 2,240 feet quite a heavy flow of bitter and salt-water, heavily charged with mineral matter, was struck. The water rose fifty feet an hour, filling the well for at least 1,700 feet. It was struck in a

hard, light-colored and sparry limestone which underlies the softer rocks already named, and which had continued from about 2,000 feet to the point now reached.

The salt-water was an unwelcome surprise to the contractor. He had based his bid for drilling upon the supposition that casing would not be needed for more than 1,200 or 1,500 feet. The contract required a dry hole, 3,000 feet deep, if the company saw fit to ask such a depth. Unwilling to attempt the exclusion of salt-water from a depth of 2,240 feet, the contractor withdrew, and the original company abandoned the well. But a few of the more sanguine or resolute members, encouraged by the recent experience of Lancaster in finding quite a promising vein of gas in a new horizon, determined to push on to lower levels. The drill was again set to work, but now through nearly 2,000 feet of salt-water. The progress was necessarily slow, but in May the new venture was rewarded to some extent by the discovery of a small gas vein at a depth of 2,385 feet. The gas was found between two beds of red rock, as in the Lancaster well. So infrequent is red rock in this part of the scale, that its occurrence here goes far towards locating the source of the gas. The Lancaster gas is certainly derived from the Clinton limestone. The Newark gas probably comes from the same horizon. Such a determination obliges us to extend the limestone column to 950 feet, which is much in excess of the sections found at Columbus, Delaware, and other points along the line. A real difficulty is involved in this construction, but still the section cannot be pronounced an impossible one.

The gas is reported as small in volume, but of high pressure. The latter fact is a natural consequence of the great depth from which it comes. It has not been utilized as yet. The volume is too small to justify any considerable outlay in tubing and packing the well in a thorough way.

This well has been quite an expensive one, and it is obvious that nothing has been found in it which would warrant such an outlay on business principles. Much more gas than is here obtained from 2,400 feet ought to be found within 400 to 800 feet at many points about Newark. The money spent on this one deep well, if used in drilling to the Berea grit or 200 to 300 feet below, would have sunk a half-dozen wells, and would probably have developed many times more gas than is here produced, though of lower pressure.

Zanesville.

The drilling done in Muskingum county has been more extensive than in any of the counties thus far passed in review. An orderly and

determined search for gas and oil has been begun here, and provision is now making to test the Berea grit within the county limits on an ample scale. Drilling privileges have been secured on large and connected tracts of territory. The structure of some of the districts that have been already tested has been determined by careful study, and to some extent by instrumental measurements.

The points of geological interest developed in the exploitation of other Ohio oil fields, and in particular the facts of the Macksburg oil field have been carefully noted, and the attempt has been made to obtain from this guidance for new work in new territory. The preliminary work of development has been mainly carried forward under the direction of W. M. Carr, Esq. But the first drilling was done by the Zanesville Heating Company, an organization of a number of business men of the city who would have the largest personal interest in the discovery of an ample supply of natural gas. This company has drilled three wells, one of them 2,000 feet deep, and a second one about 1,700 feet. The first of these wells was drilled in 1884. It was located in the valley of the Muskingum on the west side of the river, in Putnam, which is the Ninth Ward of Zanesville. The horizon of the well-head is a very little above the Lower Mercer limestone. The record of the well is given below:

Bed rock	14 feet.		
Limestone	3 " —	17 feet.	
Slate and sand-rock	35 " —	52 "	
Coal and sand-rock	15 " —	67 "	
Slate and sand-rock	21 " —	88 "	
Coal and slate	6 " —	94 "	
Slate and shale	36 " —	130 "	
White sand-rock	5 " —	135 "	
Slate and shale	15 " —	150 "	
Light slate	200 " —	350 "	
Gray sand-rock (salt-water)	70 " —	420 "	
Slate and shale	30 " —	450 "	
Light slate	210 " —	660 "	
White sand-rock	5 " —	665 "	
Dark and light slate with hard shale	175 " —	840 "	
White sand-rock (oil and salt-water)	20 " —	860 "	
Red sand-rock	10 " —	870 "	
Dark and light slate	1,149 " —	2,019 "	

Reduced to simple terms the record reads as follows:

Conglomerate Coal Measures	350 feet.
Logan group or Waverly conglomerate, containing salt-water	70 "
Cuyahoga shale	390 "
Berea shale	30 "
Berea grit	20 "
Bedford and Ohio shales	1,149 "

Drilling was suspended at 2,019 feet in the Ohio shale. The Berea grit, as appears in the record, was found at 840 feet, or about 115 feet below tide. It was of good thickness and was saturated with oil. In the judgment of some who observed it, it would have responded to a torpedo with a small but paying production. The shale series was normal in all respects so far as it was penetrated. At Newark this series is found to be 900 feet in thickness, but here it measured 1,157 feet, and the series was not exhausted.

The second well drilled by this company was located on the eastern side of the city in Section 4, Wayne township, on the land of Wm. Bishop. It was drilled dry and found the Berea grit at 847 feet.

The composition of the sandstone stratum in this well is said to have been as follows, viz.:

Coffee-colored sandstone	2 feet
Fine light-gray sand	5 "
Lighter-colored sand	2½ "
Marly white sand (33 feet)	24 "

The well was unproductive so far as high-pressure gas is concerned, but it yielded a little oil. It was plugged, but the oil still oozes out, and is collected and carried away on a small scale.

Two other wells are now going down upon the west side of the river, which, when completed to the Berea grit, will fully prove its character. They are drilled for oil, and will be treated on this basis from the first.

The fact that the Berea grit, in the Putnam well, was found saturated with oil, as reported in the record above given, was counted of sufficient importance by certain practical oil men of the neighborhood to be further investigated, and the leasing of territory, which had already been begun, was carried forward on quite a large scale through the townships of Washington, Wayne, Fall, Springfield and Newton. No further drilling has, however, yet been finished within these limits, but two new wells are located and will be put down very soon.

In the south part of the county shallow wells were drilled in large numbers in 1866–7 to the Buffalo or Upper Mahoning sandstone. The wells range from 40 to 100 feet in depth. Some of them have been maintained in feeble operation ever since they were drilled, the yield being confined to a few barrels per year. They produce an oil of 26° gravity, and of excellent lubricating character, which is mainly sold at the present time among the farmers of the neighborhood. This field is known as the Blue Rock Oil Field. The Macksburg field has shown that where one oil-rock is productive another is also likely to be, if its

texture and grain are satisfactory. In other words, the peculiarities of structure favorable to oil accumulation affect an entire series. A test of this point was recently made by Carr Brothers and Jewett, who sunk a well in 1886, in section 32, in Blue Rock township, the record of which is given below. The well was begun near the horizon of the upper Freeport coal:

To bed-rock	14 feet.
Sand-rock	5 "
Slate and soapstone	56 "
Sand-rock	14 "
Soapstone and slate	109 "
Sand-rock	5 "
Soapstone and slate	43 "
White sand-rock	8 "
Gas vein.	
Slate and soapstone	114 "
Red clay	16 "
Lime rock	10 "
Soapstone and slate	194 "
Waverly conglomerate, with break sixty feet	180 "
Slate and shale (Cuyahoga shale)	255 "
Sand-rock, hard (Buena Vista stone)	9 "
Bituminous, black shale (Berea shale)	41 "
Hard shell	1 "
Berea grit	14 "
	1,088 "
Red shale	10 "

The drill was stopped in the red shale. The well, after being torpedoed with eighty quarts of nitro-glycerine, yielded a small amount of light oil with gas enough to raise it. This small success still further inspired the confidence of the parties that are carrying forward the explorations, and other wells are soon to be sunk to this, the Macksburg sand. The region is being carefully studied with reference to its anticlinals and terraces, and it is sought to put the work that is going on in harmony with the best deductions from our one successful oil-field, namely, Macksburg. Whatever value the Berea grit may hold here will soon be made apparent. The shallow wells referred to in the preceding paragraph will be briefly treated in a subsequent chapter. (December, 1886.)

The explorations above referred to, and many more beside, have been completed in and around Zanesville since the preceding statements were made. So earnest was the wish to secure a good supply of natural gas for the manufacturing interests of the city, which are those that are especially profited by the new fuel, and so abundant was the testimony as to the presence of gas in large and troublesome amount

in the Muskingum Valley in the early days of salt manufacture here, that it was very hard to abandon the search as hopeless. But to this complexion it has come at last.

Wells have been located in all the ways that can be suggested, viz., at the caprice of the drillers, at random, in the neighborhoods of the famous "blowers" of the salt-well days, and lastly, with all the aid that geology can give, on the summits of the low arches and terraces which the spirit level reveals, and the records of all agree as to the outcome. The order and character of the strata are remarkably uniform and regular, but there is nothing whatever to break the monotonous returns of complete and unrelieved failure. There is a little gas or oil, or both, everywhere, but the fatal flood of salt water is always just at hand, and the most brilliant promise is speedily extinguished by it.

There are, of course, large districts in the county that have not yet been tested, but the most available and promising locations, which were the first to be tried, have without exception disappointed all expectations of profit. The lack of relief in the strata is obviously the ground and cause of failure. The Berea grit is thick enough and porous enough to give the best results, but it lies at the wrong angle for concentration.

Dresden.

A well was drilled at Dresden in the summer of 1886, by a local company, to test the territory. The well is a little below the horizon of the lower Mercer limestone. Its elevation above tide is about 735 feet. The Conglomerate Coal Measures, the Cuyahoga shale, blue, the Berea shale, black, and forty-five feet thick, the Berea grit, a white sandstone fourteen feet thick, the Bedford shale, red, and twenty feet thick, and the Ohio shale, mainly light-colored, are all found in normal order and appearance in the well. The surface of the Berea grit was reached at a depth of 768 feet, which shows it to be very few feet below sea-level. The rock was found to contain salt water and a small quantity of oil. The well was carried down a few hundred feet into the Ohio shale without any favorable result.

Cambridge.

At Cambridge, Guernsey county, three wells have recently been drilled, to which unusual interest is attached. This interest arises from the presence of the Cambridge Anticlinal in this general field. It will be remembered that an arch found here, although very gentle and low, is still the most pronounced arch along the entire line of the Baltimore and Ohio Railway from Zanesville to Bellaire. The effect of this

structure upon gas or oil accumulation, a subject in regard to which considerable difference of opinion still exists, can therefore be tested better here than at any other point in this portion of the state. Several demands must, however, be met before the test can be counted satisfactory. The Cambridge arch is revealed on an east and west line, the Cambridge limestone and also the Cambridge coal, as they rise to the east from Cassell's Station instead of sinking in that direction, as their normal inclination would require, furnishing the elements by which the disturbance is recognized and measured. In order that the test be satisfactory, we must be sure that the drilling is done on the highest point of the arch in the direction now noted. But another factor must also be taken into account. It is by no means certain that the summit of the fold lies exactly level. Its direction is probably southwest, as all the main structural lines of eastern Ohio follow this course, and the axis may rise and fall within narrow limits as it advances in this course. It is not enough, therefore, to be sure that the derrick shall be located on the highest point in an east and west line. To make the demonstration complete of the influence or want of influence of an arch in oil-production, it must also be shown that the well is located on one of the summits of the rolls, if such there be, in the line in which the fold extends. The summit of the arch, on an east and west line, appears from all the measures made by the Survey, to be located a little west of the town. The Tunnel Hill may be counted, in the light of present knowledge, as the highest point in the arch along the railroad. The other factor has not been determined, but it will require only a little field-work to learn whether the Cambridge limestone is higher or lower in a northeast and southwest direction than at the hill above named. It is certainly desirable, while so much random drilling is going on on all sides, that the only factor to which we can rationally give a place in our theories of oil and gas-production should be made to show whether or not it has any possibility of service and guidance in our search for this coveted source of power. The three wells already drilled at Cambridge, so far as they go, give testimony in harmony with the arch theory. No one of them was drilled on or very near the summit of the arch, but the first two were nearer than the third, and their promise and response have been the more encouraging. But, as the arch theory would lead us to expect, the gas and oil found in the Berea grit at the point where it was struck, were also accompanied with salt water. The third well is probably three miles distant from the summit of the arch, and it indicates a smaller stock of gas and oil than the two previous ones. Well No. 1 was located northeast of the town, and perhaps a half mile due

east of the summit of the axis. Its record is given below in general terms:

Soil and surface			54 feet.
Dark sand and shale	25 feet.	Lower and Conglomerate Coal Measures	401 feet.
Limestone	10 "		
Light shale	46 "		
Hard sandstone, dark-colored	3 "		
Light shale	87 "		
White sand-rock carrying oil	25 "		
Light shale	5 "		
White sand	20 "		
Shale	65 "		
White sand	25 "		
Dark shale	90 "		
Close sand, white	10 "	Logan group or Waverly Conglomerate	182 feet.
Sand with pebbles at base	100 "		
Dark shale	4 "		
Soft sand	68 "		
Light shale (Cuyahoga)			340 feet.
Black shale (Berea shale)			43 "
White sand (Berea grit)			65 "
White shale (Bedford)			5 "

The well contained several factors of considerable interest, as will be seen. The thickness of the Berea grit attracted the attention of the drillers of the Macksburg field, who saw in it the promise of a large oil-production, if other elements should prove favorable.

The well produced a considerable volume of gas, a small volume of oil, and some salt-water. The gas was in force enough to lift the oil and salt-water. The oil is a heavy oil, with a gravity of 29° B. Its production is reported to have been maintained to the present time, the rate being five to ten barrels per week.

Well No. 2 was located still further from the town in the same northeast direction, but presumably not much further from the axis than well No. 1. It struck a strong flow of gas in the salt-water sand, an experience which recalls the traditions of fifty years ago when numerous salt-wells in the Muskingum Valley were abandoned because of the interference of gas with their production of brine. The Berea grit gave no more promise in well No. 2 than in the previous well. Well No. 3 was located to the southeast, where all the geological conditions were increasingly unfavorable to either gas or oil-production.

The numerous salt-wells drilled in the Wills Creek Valley in past years have all obtained their brine from the salt-water sand or Logan Conglomerate, which holds good thickness and great steadiness throughout this entire region. It rises to day in the valley of the Licking River between Zanesville and Newark, making the picturesque cliffs between Clay Lick and Black Hand. (December, 1886).

Since the preceding statements were made a large amount of very

important experience has been accumulated in the Cambridge field, a brief account of which must be given at this point.

All the hints and suggestions that geology has to offer have finally been appropriated, and three or four wells have been located on those parts of the arch that promised best. All of these have proved failures, and the inability of any geological knowledge now in hand to serve the great practical interest of gaining a supply of natural gas in this region has been fully demonstrated. Until these last decisive experiments were made, there was good ground to hope that when proper regard should be given to the facts of local relief that the level had shown to exist, the gas-rock would be found ready to respond with a paying production. The relief was recognized as very slight, though real, but when tested by the drill it was found ineffective for the purpose desired.

The first of these wells was one located very near the Tunnel in Cambridge, by a citizens' company. The point selected was a proper one on an east and west line. It was a little less advantageous in the direction of the axis, but still was geologically more promising than any of the wells heretofore drilled in the town. The result did not in any way justify the forecast. The well was drilled to 2,000 feet and abandoned.

By far the most careful and intelligent tests that have been made of the Cambridge arch, and its effects on oil and gas-accumulation, are those of Mr. W. M. Carr. Two wells were drilled by him to the southwest of Cambridge, in the summer of 1887, in the location of which no pains were spared to render fully available all the relief to be afforded by the Cambridge anticlinal. Elaborate lines of level were run, and as the result, one well was located on the J. T. McPherson farm, one-half mile southwest of the Cambridge tunnel, and another on the northeast ¼ section 19, Westland township, on the James McCourt farm.

In the first well the Berea sand was reached at 1,045 feet. It was found to be sixty-one feet in thickness, and its constitution is as follows:

1.	Coarse, shelly, hard sand-rock	25 feet.
2.	White and fine-grained sand-rock	10 "
3.	White and gray rock, ordinary texture	26 "

In No 1 there was no sign whatever of oil or gas.

In No. 2 a small show of oil appeared, and also a little salt-water. This well was afterwards shot with forty quarts, but no value was developed in it.

In well No 2 the Berea grit was struck at 1,213 feet. The composition of this stratum here is as follows:

1.	Coarse sand, good grain and color	12 feet.
2.	Medium grain	12 "
3.	Fine, hard, white rock	3 "
4.	Average sand-rock	48 "
	Total thickness	75 "

In No. 1 there was no oil or gas; in No. 2, oil enough to grease the tools appeared, and also a little salt-water. In No. 3, a small amount of gas was found, and in No. 4 the oil showing was continued. The gas increased to a few thousand feet per day after the well was completed.

This well was shot with 120 quarts, but the result was not satisfactory. No great addition was made to the insignificant production already recorded.

Explanations can, of course, be found for these failures, but the trouble lies in the fact that there are nothing but failures to be explained.

The facts pertaining to this important line of investigations have been kindly communicated by Mr. W. M. Carr, under whose direction they have gone forward. He has brought to his search all the knowledge that is available, and he has stated the results of each experimental well with perfect candor and openness.

The Cambridge arch extends in the usual northeast and southwest direction. It presumably traverses Liberty and Monroe townships in the first direction, and to the southwest it crosses portions of Muskingum and Morgan counties.

Kimbolton.

A well was drilled to the south of Kimbolton early in 1887, by the Messrs. Luccock and other parties from Kimbolton. The well was located in Section 3, Liberty township. The record is as follows:

Well-head at Level of Middle Kittanning Coal.

Surface clays	76 feet.
Interval	314 "
Lower Mercer coal, five feet thick, at 160 feet.	
Salt-sand struck at 390 feet	173 "
Shales, gray and at bottom black (Cuyahoga and Berea shale)	417 "
Macksburg sand (Berea grit) at	980 "
Thickness of first sand	41 feet.
Shaly sand	8 "
Oil sand	8 "
Total thickness of Berea	57 "
Red shale, underlying, drilled in	50 "

The well was a failure, only a trace of gas or oil being obtained.

In a second well, undertaken soon after, a better location was selected, viz., two miles to the eastward, and in the line of the Cambridge anticlinal. The record of this well breaks the monotony of the field. It is said to produce a fair volume of gas and to gain a pressure of 300 pounds in eight minutes.

The Cambridge anticlinal has justified its name to this extent at least. Other wells are now going down in this vicinity, and there is a promise of a field of at least small proportions here.

Quaker City.

At Quaker City, on the extreme eastern side of Guernsey county, a well was drilled by a company of business men to the Berea grit in 1886. The well-head is fifteen feet below the level of the Crinoidal limestone, and about 870 feet above tide. A skeleton section, as kept by the contractor, has been kindly furnished to the Survey by Dr. E. D. Strahl. It is as follows:

At 257 feet, sand-rock.
At 259 feet, coal.
At 400 feet, a sand-rock twelve feet thick.
At 436 feet, a fossiliferous black shale.
At 438 feet, a coal seam seven feet thick.
At 460 feet, sandstone.
At 560 feet, sandstone.
At 655 feet, a sandstone sixty-six feet thick, salt-water, sand, or Logan Conglomerate.
At 750 feet, a blue shale 560 feet thick (Cuyahoga shale).
At 1,310 feet, a black shale thirty feet thick (Berea shale).
At 1,340 feet, a hard black sand one foot thick.
At 1,341 feet, the Macksburg sand or Berea grit, six feet thick.

This record shows the Berea grit to be 1,355 feet below the Crinoidal limestone, and 464 feet below tide. The elevations of this stratum at Newark, Zanesville, Cambridge and Quaker City are as follows, viz. at Newark, 254 feet above tide; at Zanesville, 115 feet below tide; at Cambridge, 215 feet below tide; at Quaker City, 470 feet below tide. The total descent from Newark to Quaker City is 724 feet. These facts are indicated in the accompanying section, which represents the fall of the strata from Columbus to Bellaire in an easterly direction.

The Quaker City well yields a few thousand feet of gas per day. A little salt-water is produced with it, but the gas has sufficient energy to remove all accumulations when it is properly handled.

The experience of the first well is not altogether discouraging to this vicinity. Other wells will probably be sunk in the near future, inasmuch as gas is much desired for use in the glass factory that has

recently been established at Quaker City. So far as the elevations taken through the vicinity show, the strata to the westward appear to hold a monotonous descent, and no indications have been found in this immediate neighborhood of the suspensions or interruptions of the dip that we are learning to regard as indispensable to large accumulations of gas. Somewhat more favorable indications are apparently found about three miles to the eastward. At that point a small terrace appears to be developed. If further drilling is attempted here in the absence of other determining circumstances, this terrace should be tested.

F. Deep Wells of Fairfield, Perry and Morgan Counties.

Lancaster.

An interesting and important well is now being drilled at Lancaster, Fairfield county, by a company of citizens, in order to properly test their territory with reference to gas or oil. The well is located in the valley of the Hocking river, a little below the railway station. Its elevation above tide is 812 feet. The divisions of the well record, though unmistakable in the main, are not in all cases sharply defined in the accounts that are accessible. As reported by Mr. Albert Smith, the contractor, the leading facts are as follows:

Drift	132 feet.	
Cuyahoga shale and Berea shale	268 "	
Berea grit	20 "	
Shales, red, blue and dark	430 "	
Black slate	200 "	
Soft limestone	100 "	or more.
Hard limestone	600 "	to 700 ft.
Red-rock, interbedded with hard calcareous bands, beginning at..	1,810 "	

The surface of the Berea grit is here 412 feet above tide. The first bed of red-rock, thirty feet in thickness, was struck at 1,810 feet, as noted above. It was succeeded by three beds of sand, so-called, at intervals of twenty or thirty feet, and below these a second red-rock was struck.

The sinking of the drive-pipe through the 130 feet of drift, above noted, was slow and expensive. A large tree was struck nearly endwise at a depth of forty feet, which proved very troublesome, and lower down beds of quicksand occurred in considerable amount, which were hard to pass. The Berea grit was found in fair volume, but essentially unproductive. The shales were soon passed, but the limestones below

proved hard and stubborn, and the drill descended through them slowly. The lower surface of the limestone does not come out very distinctly in the records that are accessible, but a red shale was struck at 1,810 feet, interbedded with which were hard calcareous bands that bruised the bits out of gauge like sandstone. Gas was found in a considerable volume in this last-named series, and especially in a hard stratum at 1,957 feet. There is some question as to the geological source of the gas—whether derived from the Clinton or Medina horizon, with the probabilities greatly in favor of the former. Both contain red shales. The progress of the well will, perhaps, clear away the uncertainty. The flow of gas in the well was measured by the anemometer at the casing head on February 10, 1887, and the amount of daily production was found to be 74,880 cubic feet. If the gas were obliged to issue from a two inch pipe, probably not more than 60,000 feet per day at most would be produced. Salt water appears to enter the well in connection with the gas. At the date of measurement there was thought to be not less than 200 feet of it in the well.

Great interest has been excited by the success that Lancaster has achieved in finding a deep source of gas, and the drilling of deep wells will be greatly stimulated thereby throughout the entire region. It is too early to decide what the value of the discovery is. (March, 1887).

The later records of this well and of two subsequently drilled are full of interest. Drilling was continued in the first well for a comparatively short distance below the gas vein, but the distance proved long enough to identify the horizon beyond all question. A bed of red rock was the most conspicuous element in the new portion of the section, and this, on examination, proved to be the iron ore of the Clinton horizon, the most definitely characterized bed in the whole column of Ohio. It was thus learned that the gas in question is derived from a bed of crystalline light colored limestone, included between two beds of red rock, all of which are of Clinton age.

The analysis of the gas rocks also throws a good deal of light upon its place in the scale. Its composition is as follows, viz.: (*Lord.*)

Carbonate of lime	80.60
Carbonate of magnesia	4.57
Insoluble matter	8.65
Oxide of iron and alumina	3.50

To those who are acquainted with the composition of the several limestones of our scale in their outcrops, these figures will be significant.

There is but one limestone in the list that agrees with them, and that is the Clinton limestone of southwestern Ohio.

A chemical composition of this character will scarcely be found compatible with very large gas production, if we can judge from the experience of the Findlay field. If such production is realized here it will probably be found that the rock has become dolomitic in character.

A number of other analyses of the drillings of this well are appended here. No. 1 belongs 100 feet or so above the gas-rock, and represents the Niagara limestone perfectly. Nos. 2 and 3 show the composition of the shales that carry the Clinton ore. The analyses are as follows: (*Lord*)

	1	2	3
Carbonate of lime	54.13	30.32	27.01
Carbonate of magnesia	42.86	2.11	3.17
Insoluble matter	1.30	30.10	38.15
Oxide of iron and alumina	.50	24.60	26.20

In the last analysis, the iron constituted 11.2 per cent. of the combined product.

The Clinton limestone has long been known to be petroliferous. It is decidedly so in its outcrops in southern Ohio. Especially in Montgomery and Preble counties, notable quantities of petroleum are found in quarries of the limestone and in springs that issue from it. The surface indications led to the drilling of deep wells in both these counties during the oil excitement of twenty-five years ago, but the surface indications were all that was in the field, and deep drilling was not rewarded in any way.

More recently the Clinton limestone has been found a source of gas and oil in northern Ohio. The Fremont shallow wells derive their supplies from this horizon, and a well in Wood county has been already reported which produces thirty to forty barrels of oil per day from the same series (page 233).

Still, the discovery of so considerable a gas vein as Lancaster has obtained in the Clinton was altogether unexpected. The same series had been penetrated during the two preceding years, scores of times, in the counties to the west and north, without realizing any value whatever, and the conclusion already stated, that but one horizon of gas belongs to any one locality, was counted fully warranted by the facts.

This conclusion is not really vitiated as yet, for although Lancaster is located on the edge of Berea grit territory, this stratum has no apparent value here. It has furthermore been shown that the Trenton limestone loses its productive power in this portion of the state on two counts, viz., its chemical composition and its depth below sea, involving also its lack of suitable relief. Under the circumstances, the discovery of a new source of gas, large enough to be respectable, in a field so well tested already, was certainly surprising. It seems to leave but little value to geological forecast.

The well above described was torpedoed with 100 quarts of nitroglycerine during the summer, and its flow was said to be increased several fold by the operation. It has been utilized in the shops of the Hocking Valley Manufacturing Company. Its yield has not been determined recently, but it is asserted that volume and pressure are well maintained. The supply is not quite adequate to the demands of the works into which it has been introduced, at least with the present appliances for using it.

The history of the two wells subsequently drilled will now be briefly given.

The second well, located near the base of Mt. Pleasant, has been recently brought in and proves to be of great importance and significance. In its record, it agrees in all essential particulars with well No. 1. It is a little more than a mile northeast of the first well and is located upon ground forty or fifty feet higher. The design was to strike the outcrop of the rock and thus avoid the trouble from the drift, before experienced, but fifty feet of drift clay were found at this point also. The Berea grit had a small showing of gas, but it also carried salt-water, which was cased out at about 450 feet. The descent through the shales and upper limestones was uninterrupted until a depth of 1,855 feet was reached. Here a strong flow of limestone brines, rank with chlorides of sodium, calcium and magnesium, was struck. It came from the top of the Niagara shale, which appeared here as thirty feet of soft drilling. Immediately below, hard bands were found interstratified with thicker beds of shale. It is probable that this change marks the beginning of the Clinton series. By this determination, its upper surface was reached at 1,885 feet. The well was cased to 1,900 feet with $5\frac{5}{8}$-inch casing. This is the deepest string of large casing known in the state. In the Cleveland well the length is 1,850 feet. A band of red shale was found at about 1,950 feet, and at 1,989 feet the crystalline limestone, which proved the gas-rock in well No. 1, was reached. It re-

sponded the moment it was tapped by the drill with a vigorous production of gas. This sheet of limestone proved to be about ten feet thick, and was followed by another band of red rock, in which drilling was suspended. The flow of gas, as measured from the casing by the anemometer, October 14, 1887, was found to be 792,000 cubic feet per day, or in round numbers 800,000 cubic feet per day.

The gas appears to differ from the Trenton limestone gas in having less sulphuretted hydrogen and greater illuminating power. Analysis may not, however, confirm these observations. The well is entirely dry, and is in all respects in perfect condition.

Well No. 3 was brought in a few days after No. 2, and proved even more vigorous than its predecessor. It is located on an outcrop of the Logan Conglomerate, a little more than a mile southeast of the city. The three wells thus mark the corners of a triangle, and it would seem reasonable to count, at least, the territory included within its boundaries as gas territory. The further limits of the field will necessarily await the definition of the drill.

The well-head was about twenty feet higher than the location of No. 1, but the gas-rock was not reached until a depth of 2,020 feet was attained. In No. 2, the gas-rock was found at a greater elevation than in No. 1, but in No. 3, more than sixty feet lower. The last well proves to be the best, a result which the present scanty series of facts leaves unexplained. The level at which it was struck would seem to place it at a disadvantage.

The well is tubed with 4¼-inch pipe from top to bottom. The same strong stream of salt-water reported in No. 2 was found here also, near the level of the Niagara shale. This last-named stratum was found to be about fifteen feet thick. In addition to the 4¼-inch pipe, the regular casing extends to the Berea grit and below. The Devonian limestone was reached at a depth of about 1,150 feet. The Logan Conglomerate continued as a gray sandstone for 145 feet. There were several belts of red rock above the gas vein. The gas-rock proper is reported as at least fifteen feet thick.

Well No. 2 was measured on October 14th, and the daily product from the 4¼-inch pipe was found to be 878,000 cubic feet. Like results were obtained by Prof. G. W. Welch a day or two before this. The flow would doubtless have been 1,000,000 feet if measured from a 5⅝-inch pipe.

The closed-pressure of the wells has not been determined, but there is good reason to expect that it will be high. The gas is derived from a depth of nearly, or quite 2,000 feet below the surface, and about 1,100

feet below sea-level. A pressure far in excess of the pressure of the Findlay field is to be expected here.

The three wells now completed are understood to have cost about $6,000 each. Now that the series and the conditions are understood, it will probably be possible to reduce this amount, to some extent, in future drilling. The large casing will not again be continued to the limestone brines, but it will have fulfilled its office when it has taken proper care of the brine of the Berea grit at 400 to 500 feet below the surface. The deeper brine is to be shut out at a depth of nearly 2,000 feet below the surface.

The facts now given, viz., that the two wells completed in October, 1887, are yielding 1,700,000 cubic feet of dry gas per day, attest the importance of the new field. If the gas proves fairly permanent, and all the indications seem favorable at the present time, Lancaster is sure to reap very great advantage from the discovery which the energy and persistency of a few of her citizens have wrung from unwilling nature.

A new horizon of gas and oil is to be added to the scale of southern Ohio by this discovery. What is its significance and promise? Answers have been already given to this question in the preceding pages of this chapter. The records herewith published show that the Clinton series has proved barren of all production in the test wells of Columbus, London, Washington C. H., Circleville, Chillicothe and Carroll.

In Newark, a small production has been realized from it. A well which is being drilled at Baltimore, Fairfield county, is down near to or beyond this horizon at the present time, and testimony of one sort or another will soon be obtained from it. It is evident that the value of the discovery has been already largely discounted in the adjacent regions, but still a new impetus will be given to the work of exploration.

By referring to the line of sections described on page 318, it will be observed that a gentle uplift of the series appears at Lancaster. It is explained in the account that is given of it as depending on the approach to the western outcrop of the Berea grit, but it is possible that the fact has a different significance, and really stands for a fold of small force that crosses the country here and presumably in a northeast and southwest direction.

One advantage will, perhaps, result from this discovery to the regions now under consideration. The Clinton limestone will take the place, in the popular demand for deep drilling, of the Trenton limestone, and a much needed rest will be secured for this last-named overworked stratum.

The drill can be made to reach the Clinton series in a great many places where it is almost chimerical to undertake to reach the Trenton

limestone. The eastward descent of the entire series, through this part of the state will, however, soon carry the new horizon to the same impracticable depths in this direction.

Carroll.

Carroll followed the example of Lancaster, by drilling a deep well in the summer of 1887. A skeleton record, kindly furnished by Dr. J. G. Nau, gives the facts to a recent date. They are as follows:

Drift	260 feet.
Shales	615 "
Limestone	335 "

The Berea grit is due in the space occupied by the surprising series of drift deposits that appear here, aggregating 260 feet. No value had been developed in the well at the date of the last report. A depth of 2,300 feet had been reached, which is 600 feet or more below the horizon of the Lancaster gas. The Trenton should be struck at about 2,800 feet.

McCuneville.

At McCuneville, in Perry county, several wells were drilled a number of years since to the Berea grit and below, in a search for salt-water. The wells of this locality reach the Berea grit at a little more than 800 feet in depth, and they reveal a normal section in all respects. The Berea grit is here about ten feet thick, and about forty feet below sea-level. It is 820 feet below the lower Mercer limestone, and 960 feet below the great vein, or Middle Kittanning coal which is mined in the hills above the well-head. The Berea grit yielded a weak brine, from which it was undertaken to manufacture salt, but even though the cheapest of fuel, viz., the slack of the mines near by, could be used in the manufacture, the business proved unsuccessful, owing to the weakness and small quantity of the brine. A small volume of gas came into the wells in connection with the salt-water, and is still rising through the whole column of water in such volume that it can be lighted at the well-head.

The record of one of these wells, as copied from the log of the proprietors, is given below. It was kindly supplied by F. G. McCune, Esq.:

At 280 feet, a sand-rock with salt-water was struck. This continued for 98 feet, with a few small interruptions of shale.

At 390 feet, struck gray rock.

At 450 feet, struck gray sand with salt-water and some gas.

At 600 feet, struck hard shell-rock (Cuyahoga shale).

At 795 feet, struck black slate, 19 feet thick (Berea shale.)
At 814 feet, struck white sand, 13 feet thick, with salt-water and gas (Berea grit.)
At 827 feet, struck red shale (Bedford shale), 8 feet thick.
At 835 feet, struck hard gray shale, 50 feet thick.
At 892 feet, struck black shale which continued, with changes, from hard to soft, and also in color to 1,368 feet, making 541 feet of shale below the Berea grit.

Malta.

In Morgan county, a large amount of salt-well drilling was done at an early day, and within the last twenty years many wells have been drilled in the search for oil. Most of these wells are shallow and obtain their oil from the Coal Measure sandstones. These will be described in another chapter, but several of the later have been drilled to the Macksburg sand, or Berea grit.

The most remarkable flow of gas known in the county of late years was derived from the "salt sand" or Logan Conglomerate, in a well back of Malta. A large volume of gas was set free here originally, and the flow was maintained for many years with a measure of importance. It was early utilized in a small way, and has done its full share of service in familiarizing the people of the valley with the presence and advantages of natural gas. In one respect it has proved misleading. To most people it seemed safe to draw the conclusion that since gas had been found in large quantity before the world had learned to appreciate its wonderful value, and therefore when its discovery was unwelcome, an abundant supply would be sure to be found whenever a definite search should be made for it. The search has been made at Malta and McConnellsville recently, but so far as learned no supplies comparable with the old ones have yet been obtained.

Eaglesport.

It is to Mr. W. M. Carr that we owe the most methodical and intelligent investigations of the capabilities of the Berea grit as an oil or gas-rock in Morgan as well as in Muskingum and Guernsey counties. During the last two years he has carried on a series of instrumental measurements through portions of the western half of Morgan county, and has sought to locate all the structural displacements that would promise service in the way of gas or oil accumulation. He has traced with more or less certainty the light folds of Guernsey and Muskingum counties to the southward, and has tested one or more of the points that seemed most promising as possible reservoirs.

In a well thus located in Deerfield township, N. W. ¼ Section 2, on Island Run, the Berea grit was found in a perfectly normal section at

1,134 feet. It was 19 feet thick, and there was a good showing of gas and oil in it. The well was shot with eighty quarts, and gave a good reaction, but afterward "bridged" 300 feet from the top. The bridge was broken, and it was then found that the shale above the grit had fallen in and some days were consumed in getting the well clear. The work was accomplished, but there was nothing to render it valuable. Salt-water soon made its appearance, and another failure was added to a list already discouragingly long and one-sided.

Joy P. O.

Among the remaining wells, the most important are two that are located near Joy postoffice, on the south line of the county. One of these was drilled in 1885, and the other in the winter of 1886–7. The record of the first is not at hand, but it was drilled by parties thoroughly familiar with the Macksburg field, who found every element in the well normal. The well was counted, when the Macksburg sand was struck, fairly favorable in its indications, but although the rock contained oil in great or less quantity, it did not generate gas enough to raise it to the surface, and the pump was never applied. Defective packing was charged upon this venture by some who claim to know the facts. The second well is now 800 feet down, and will doubtless be finished in time for record in the present chapter.

The well in question found the Berea grit 1,240 feet below the Ames or Crinoidal limestone, and full of salt-water. It was drilled to a depth of twenty feet without being exhausted. These facts have been kindly furnished by J. A. Lovell, Esq.

The presence of oil in small, but fairly continuous, supplies from shallow sand-rock in this field has led to the deep drilling which is here reported. Production from similar shallow wells was the forerunner of the later and larger development of the Macksburg field, and the hope is entertained by the drillers that the analogy will hold true in Morgan county.

There is room enough in this general region for many oil-fields like Macksburg. The cover is ample, and the underlying rocks are known to be regular in composition, and all that is required is disturbed structure similar to that of Macksburg. Without doubt such structure exists in a greater or less degree throughout this region. In fact, it is impossible to conceive of the rocks as all taking their final places in the scale without such disturbance. The presence of shallow oil would seem to furnish the best clue to follow in locating such districts.

G. Deep Wells of Hocking, Vinton, Jackson, Scioto and Lawrence Counties.

Logan.

Considerable drilling has been done for oil in Hocking county. At Logan three wells were sunk in 1865 and 1867, all of which proved productive of oil and gas in at least a small way. The first well was located on the Baird farm, a short distance below the town. The horizon of the well-head is the characteristic exposures of conglomerate and sandstone that have given a name to a great formation in our geological scale, the Logan group, of the Sub-Carboniferous Age. The records of the first two wells are as follows:

Record of Lower well drilled 1865—

Drift	Gravel	11 feet.
	Quicksand	9 "
	Clay	2 "
Gray sand		10 "
Blue slate		48 "
(Water at 50 feet).		
White sand		10 "
Cuyahoga shale	Blue slate	70 "
	Sand-rock	1 "
	Blue slate	21 "
	Slate	23 "
	Sand-rock	22 "
	Soapstone	68 "
	Amber-stone	30 "
	Blue slate	27 "
	Shale	63 "
	Sand-rock	45 "
	(Salt-water at 440 feet).	
	Shale	20 "
	Soda-rock	113 "
(Salt-water at 520 and at 590 feet).		
Bituminous black shale (Berea shale)		37 "
(Oil and gas at 626 feet).		
Sand-rock (Berea grit)		26 "
(Salt-water at 640 feet).		
Red shale (Bedford shale)		114 "
(Trace of oil at 770 feet).		
Ohio shale	Black shale	73 "
	Gray slate	73 "
	Sand-rock	40 "
	Soda-rock	46 "

Upper well, drilled in 1866—

To rock	26 "
Pebble rock (Logan group)	12 "

Gray slate	104 feet.		
Shale	6 "		
(Water at 148 feet).			
Sand-rock	10 "		
Shale	65 "		
Sand-rock	53 "	Cuyahoga shale	530 feet.
(Water at 275 feet).			
Soapstone	88 "		
Shale	72 "		
Soda-rock	132 "		
Black shale (Berea shale)			40 feet.
(Hole reduced to five inches at 601 feet).			
Sand-rock (Berea grit)			40 "
(Oil at 609 feet).			
(Salt-water at 611 feet).			
Red shale (Bedford shale)			27 feet.

The third well was located on the Clear Fork of Scott's Creek, a half-mile west of the town, in 1867. Its record is as follows:

Drift, sand and gravel			28 feet.
Pebble rock			12 "
Gray rock	105 feet.		
Shale	3 "		
Sand-rock	12 "		
Sandy shale	65 "		
Sand-rock	33 "	Cuyahoga shale	522 feet.
Soapstone	88 "		
Sandy shale	72 "		
Soda-rock	132 "		
Black shale (Berea shale)			59 feet.
Sand-rock containing oil	2 feet.	Berea grit	41 "
Sand-rock	39 "		
Red rock (Bedford shale)			27 "

These accounts are altogether intelligible. A question might be raised as to the upper boundary of the Cuyahoga shale, but the composition of the several records renders the present division the probable one. The Berea grit crops out a few miles to the westward, and, in fact, the entire series can be studied with unchanged characteristics in outcrops, so that there is nothing ambiguous or uncertain in the records of the wells.

The last well has yielded oil ever since it was drilled. Its production has been insignificant, but steady. Salt-water is delivered with the oil, the gas never having lost the energy necessary to raise both to the surface. The oil is of lubricating quality, of 24° gravity, and the production is confined to one or two barrels per month.

It will be seen that the Berea grit, in these wells, has good thickness, and the facts seem to warrant the expectation of larger stocks of oil or gas near at hand than any that have yet been found. The surface of the Berea grit is about 100 feet above tide in this district.

A well drilled in the summer of 1887, at Logan, obtained a vigorous

but short-lived flow of gas from the Berea grit, which was struck at 620 feet. The first blaze is said to have been thirty feet high. At six feet in the rock the unfailing salt-water was struck.

Drilling was continued thereafter through the shale series, but no recent facts pertaining to the work have come to hand.

Bloomingville.

Three wells were drilled in the vicinity of Bloomingville, Benton township, about the same time that the Logan wells were drilled. The following is the record of one of these wells. It was kindly furnished, some years since, by David H. Strous, of Laurelville. The well was begun fifty or more feet below the upper surface of the Cuyahoga shales. The section, as reported, is this:

Slate	13 feet.		
Gray sandstone	10 "		
Soapstone	50 "		
Soapstone and sandstone	18 "		
Soapstone	59 "		
Rock	32 "	Cuyahoga shales	445 feet.
Soapstone	6 "		
White sand-rock	15 "		
Soapstone	48 "		
Gray sand-rock	64 "		
Soapstone	11 "		
Bituminous shale (Berea shale)			39 feet.
Oil and salt-rock (Berea grit)			35 "
Soapstone	12 feet.		
Red soapstone	81 "	Bedford shale	109 "
Soapstone	16 "		
Black slate			

Sandy shales were evidently confounded by the driller with sand-rocks in this record. The series is unmistakably Cuyahoga shale, and in the outcrops of this formation, which cover the country for many miles to the westward, there is no such preponderance of beds that deserve the name of sand-rocks as the record here contains.

The Berea grit proved productive here on the same scale as already described in the Logan wells, a barrel per month of 24° oil of lubricating character being produced for a number of years. The record of still another experimental well and of later date is given below. In 1882, a company, styled the Eureka Oil Company, Limited, drilled a well near those already described. This well struck the oil-sand, or Berea grit, twenty-six feet thick at 500 feet, but, inasmuch as disappointment had occurred in regard to the extension of a railroad line through the valley, which would furnish facilities for moving oil, in case it were reached, the well was plugged, but a few months thereafter the gas-pressure

blew out the plug, and the well has since been flowing oil to the present time. The production is not large.

Vinton Township.

There is but a single record at hand of drilling in Vinton county, but this record has become quite famous, and is, perhaps, as widely quoted as the record of any well of the state. The well in question was drilled in the oil excitement of 1867, on section 4, Vinton township, on the land of John Calvin. Gas in great volume was struck at a depth of 490 feet. The well-head was near the horizon of the Ferriferous limestone. It is not certain what rock was the source of the high-pressure gas released by the drill at this point. It could not have been the Berea grit, unless a decidedly abnormal section exists here, and a more probable source is the Logan Conglomerate, or salt-water sand of the Hocking Valley. The figures would not be far out of the way for the summit of that section. This rock, it will be remembered, has yielded at many points a very vigorous supply of gas. The well in question produced a small amount of salt-water in connection with the gas. When first struck the flow of the gas was very violent. It was ignited from the boiler fire forty feet away, and burned to a height variously estimated at 75 to 200 feet. Prof. Andrews, of the Geological Survey, visited the well in 1870, three years after it was completed, and he described the gas as then issuing with great force, and declared that there was no apparent diminution in the supply from year to year. (Geology of Ohio, Report of Progress 1870, page 118.)

These facts are of interest at the present time, and seem to point to minor axes of disturbance through this region, in connection with which gas and oil would be sure to be accumulated. The Berea grit has not been tested so far as is known in Vinton township.

Jackson Court House.

In Jackson county a deep well was drilled in the early part of 1886. It has not been possible to obtain a complete record of this drilling, but a few facts have come to hand. The Berea grit is known to have been struck at a depth of about 700 feet, or not far from the sea-level. It was covered with the black Berea shale, and immediately underneath it the chocolate-colored Bedford shale was found. In other words, the section was a normal and unmistakable one. The Berea grit yielded a small amount of gas. The shale was entirely penetrated in the descent of the drill, and the Upper Silurian limestone was reached at 1,500 or 1,600 feet. No addition to the gas was derived from measures below the

Berea horizon. The pioneer salt-wells of the state were located at Jackson Court-house, and they were known in the early history of Ohio as the "Scioto Salines." The salt-water was derived from the Coal Measure Conglomerate which often makes the floor and the walls of the Salt Creek valley in this part of the county. The salt-wells were all shallow and their brine was weak and impure. The manufacture served a good purpose at an early day, but it soon came to an end. No deep drilling has been done in the county so far as is known, except the single well referred to above.

Portsmouth and Sciotoville.

Several tests of the rock series, for gas or oil, have been made in Scioto county within the last few years. A well was drilled at Sciotoville in 1875, by W. Q. Adams, Esq., to a depth of 800 feet or more, and later a deep well was drilled at Portsmouth, also by Mr. Adams. The latter test was quite thorough, as far as it went, all proper conditions for noting gas being observed in the drilling. The Sciotoville well was begun near the summit of the Cuyahoga shale. It found the Berea grit at 500 feet, or thereabouts, and obtained a moderate flow of short-lived gas. The Portsmouth well was drilled in 1885. It was begun in the Cuyahoga shale, and near the base of this stratum. The record is as follows:

Loam, sand and gravel	70 feet.
Sandstone, Buena Vista stone	50 "
Berea shale, black	30 "
Berea grit, sandstone	50 "
Bedford shale, red	50 "
Ohio shale, mainly black	560 "
Lower Helderberg, Niagara and Clinton limestones	675 "
Medina shale, red	50 "
Hudson River shale and limestone	465 "
	2,000 "

From samples of drillings, obtained at 885 feet in reaming the well, which are unmistakably Waterlime or Lower Helderberg, it is judged that the Corniferous limestone is still excluded from the section by the overlap of the Ohio shale. The limestone was found full of salt-water, the strongest and most persistent vein being struck at 1,000 feet. The casing was necessarily set deep, viz., at 1,120 feet. The well was carried down into the Hudson River, or Cincinnati group, but it stopped short of the Trenton. No gas-bearing rocks of high-pressure were found in the descent, though more or less gas was struck in every stratum. The well is to be drilled 1,000 feet deeper forthwith, or to the Trenton limestone.

Ironton.

Ironton, in Lawrence county, has been especially desirous of securing the new fuel, its leading business interests being of a sort that are most affected by the use of natural gas in other fields. A very thorough test of one locality, at least, has been made by the Belfont Iron Works. This company has been engaged, during parts of the last three years, in drilling to a depth seldom reached in such explorations. The well was begun in 1885, and it reached a depth of 2,000 feet in that year. It is now being carried still deeper. Its record is clear and unambiguous for more than 2,000 feet. The order of facts brought out differs in some respects from what would have been expected from a study of the outcropping formations. On this account, this well became a valuable guide for such explorations in this part of the state. It was begun at a point 145 feet below the limestone ore, or ferriferous limestone horizon, and 215 feet below the Middle Kittanning or Sheridan coal. A carefully kept record was preserved by the company, and kindly furnished to the Survey. Since this well has been drilled to the Trenton limestone, according to a rather halting and uncertain determination, it has been counted proper to include an account of it in Chapter III. A discussion of the facts connected with it is to be found on page 304.

H. Deep Wells of Meigs, Gallia, Athens and Washington Counties.

Pomeroy.

Pomeroy is the great center of salt-production in the Ohio Valley and a great number of wells have been drilled to the salt-water horizon in years past. The Carboniferous and the Logan Conglomerate seem to be united in one great mass of coarse and sometimes pebbly sandstone in this part of Ohio, and from some portion of this compound stratum the brine is derived. It was accompanied with a considerable amoun of gas in early days, enough in many cases to cause the water to flow from the well-head, but this state of things has long passed, and the pumps are obliged to reach deeper for their supply as time goes by. Traditions of a deep-lying and valuable coal seam have been kept alive in the community by salt-well drillers from an early day. In 1885, a hole was drilled with special reference to determining the presence of such a seam, and its existence was definitely disproved by the record, at least at the point where the drill descended. The record of this drilling was furnished by F. Dabney, Esq., under whose direction the work went forward. The depth of the drilling was 767 feet, and inas-

much as questions of the same character may be raised again, the record which is verified at every point by samples carefully preserved, will be printed here:

Record of a Well Bored at Pomeroy, Ohio, to a Depth of 767.53 Feet below the Pomeroy Coal Seam.

June 11, 1883. Top of well is 64.13 feet below the Pomeroy coal seam, and 631 feet above sea-level.

27 feet 8 inches of clay, then 18 inches of hard sandstone.
58 feet 9 inches—Changed to red soapstone, 29 feet 7 inches thick.
61 feet 7 inches—2 feet 11 inches of blue sandy shale.
67 feet 4 inches—5 feet 9 inches of red soapstone.
72 feet 9 inches—Fire-clay, 5 feet 5 inches.
87 feet 8 inches—Blue sandstone, 14 feet 11 inches, contains much pyrites.
130 feet—Red soapstone, 42 feet 4 inches, with small nodules of limestone.
133 feet—Hard white rock, 3 feet.
138 feet 5 inches—Sandstone, 5 feet 5 inches; at 134 feet, nodule red iron-ore.
178 feet 3 inches—Gray shale, 39 feet 10 inches. At 170 feet shale was black.
182 feet—Sandstone, 3 feet 9 inches.
204 feet 6 inches—Shale, 22 feet 6 inches.
219 feet 6 inches—Sandstone, coarse, 15 feet. At 120 reduced hole from $4\frac{3}{4}$ to $3\frac{7}{8}$.
221 feet 6 inches—Fossiliferous limestone, 2 inches, very hard.
232 feet—Greenish shale, 10 feet 6 inches.
265 feet—Whitish shale, 33 feet.
267 feet—Hard limestone, 2 feet.
270 feet 11 inches—Gray shale or fire-clay, 3 feet 11 inches.
279 feet—Dark shale, 8 feet 1 inch. In this shale a few inches of coal.
280 feet 1 inch—Hard red iron-ore, 1 foot 1 inch.
280 feet 1 inch—Dark shale, gritty, 9 feet 7 inches, hard, with coal streaks.
295 feet—Gray shale, 5 feet 4 inches.
300 feet—Sandstone, 5 feet.
306 feet 1 inch—Blue shale, 6 feet 1 inch.
317 feet 7 inches—Coal, 1 foot 6 inches.
315 feet 7 inches—White soapstone or clay, 8 feet.
367 feet 11 inches—Sandstone, 52 feet 4 inches. Upper part fine and gray, lower part of seam coarse and white.
377 feet 11 inches—Dark shale, 10 feet.
382 feet 11 inches—Limestone, 5 feet.
441 feet—Sandstone, white, fine, 58 feet 1 inch. Cuts very free; 4 feet per hour.
446 feet—Limestone, 5 feet.
465 feet 3 inches—Coal, a thin streak.
465 feet 3 inches—Sandy shale, dark, 19 feet 3 inches.
499 feet 2 inches—Brown sandstone, 33 feet 11 inches.
505 feet—Dark bituminous shale, 5 feet 10 inches.
516 feet—Gray shale, 11 feet. Streaks of coal.
540 feet—Brown sandstone, 24 feet.
550 feet—Gray soapstone, 10 feet.
600 feet—Sandy shale, 50 feet. At times sharp grit.
611 feet—Bituminous shale, 11 feet. Thin streaks of coal.
621 feet 4 inches—Gray shale, 10 feet 4 inches.
684 feet—Sandstone, pebbly, 62 feet 8 inches. Very hard.
691 feet—Blue shale, 7 feet. Bituminous.
13 feet 5 inches—Sandstone.

Gallipolis.

A county town in Ohio that has not drilled a deep well during 1886–7 is a rare exception to the general rule. Gallipolis complied with the prevailing fashion and made an unavailing search for gas or oil, drilling to a depth of nearly 3,000 feet. The record has not been obtained, but it is understood that the well showed no features different from those already made so familiar in the recent explorations of southern Ohio.

Nelsonville.

In Athens county a similar state of things exists to that described in Meigs. Salt-wells, by the score, have been drilled to the Logan Conglomerate, which is reached at Salina in the Hocking Valley, at a depth of 570 feet below the surface, or 460 feet below the Nelsonville (Middle Kittanning) coal. A well is now in progress at Nelsonville, in which deeper horizons have been reached. It has not been found possible to obtain a reliable record of the well, but it is claimed that the Berea grit was passed here in a normal section at a depth of about 950 feet, which would place it 200 feet or more below tide. It contained a small amount of gas, but no value has been developed by the well thus far.

Marietta.

In Washington county there has been more activity in drilling deep wells than in any other county of southern Ohio, at least outside of Noble county. This activity has been inspired by the great success of the Macksburg oil-field, which extends into Washington county in its northern townships. The search for gas to be used in Marietta has, in particular, been earnest and resolute. With great supplies of gas going to waste all around them, it has seemed to enterprising citizens of this town that some reservoir must be available at hand, and accordingly the drill has been set to work and kept at work at numerous points in the vicinity. Several wells of unusual depth have been included among the last put down. The order of the strata, as far as the Macksburg sand or Berea grit, is now as well settled in this part of the state as the routes to Pittsburgh or Cincinnati by the Ohio river, and to this familiar portion of the record, additions have recently been made of 1,200 or more feet below the Berea grit. This descent is all included in the great shale series. It is very uniform in composition, varying only in color for most of the descent, as the work advances. The hope has been that a deeper oil-sand would be struck, imbedded in these

shales. There would be nothing to occasion surprise in such a result. The Venango sands of Pennsylvania all belong below the horizon of the Berea grit. To the northward we are sure that no important representation of these elsewhere prolific beds exists. The shale series is absolutely unbroken, so far as the interruption of conglomerates or even sandstones is concerned, but it may very well prove different in the Ohio Valley. Recent explorations southwest of Pittsburgh have shown important stocks of oil and gas in the Gordon sand, 300 feet below the Gantz sand, the latter of which is probably the equivalent of the Berea grit. Mr. Benjamin T. Nye has found on the West Virginia side of the river a thin sandstone with a trace of oil at a depth of about 300 feet below the Macksburg sand. In a well recently drilled by Mr. Nye on the Ohio side, with especial reference to these possibly deeper sands, the record of which, with accompanying samples, was kept with great care, neither oil nor gas was found of any value at these great depths, but several thin sandstone beds occur in the uppermost 300 feet of the Ohio shale. In the lowermost 750 feet the records shows the shale to be unbroken.

The record of Cherry Farm well, No. 2, drilled to the Macksburg sand, is given below, and this will be followed by the record of the Rake well last described, in which the section is continued from the Macksburg sand downwards for 1,259 feet without reaching the bottom of the shale.

Log of Well of Marietta Gas Co., No. 2, Cherry Farm.

20 feet.	Mud and clay	20 feet.
4 "	Gravel	24 "
6 "	Red mud	30 "
20 "	Limestone	50 "
15 "	Red sand	65 "
85 "	Slate	150 "
20 "	Red sand	170 "
95 "	Red rock	265 "
35 "	White sand	300 "
100 "	Red rock	400 "
20 "	White slate	420 "
150 "	Red rock and slate	570 "
30 "	Red sand	600 "
10 "	Red mud	610 "
10 "	Gray sand	620 "
20 "	Black slate	640 "
30 "	White sand	670 "
15 "	Slate	685 "
80 "	Sand	765 "
105 "	Slate	870 "
30 "	Sand	900 "

5 feet.	Slate	905 feet.
15 "	Blue sand	920 "
5 "	Coal	925 "
25 "	Slate	950 "
70 "	Black and blue sand	1,020 "
55 "	Slate	1,075 "
75 "	Sand	1,150 "
235 "	Salt sand	1,385 "
20 "	Dark-gray sand	1,405 "
10 "	Slate } (Cuyahoga shale) {	1,415 "
285 "	Shale } (Cuyahoga shale) {	1,700 "
55 "	Black shale (Berea shale)	1,755 "
5 "	Sand, Macksburg (Berea grit)	1,760 "
20 "	Shale and gray slate	1,780 "
1,780 "		

Log of Rake Well.—Commenced Drilling March 18, 1886.

	Feet.
Top of Macksburg sand	1,681
Bottom of Macksburg sand	1,685
Light slate and shells	1,713
Blue shale with slight changes in color.	
Hard sand	1,939
Soft brown sand	1,948
Slate and shells	2,042
Slate, no shells	2,058
Slate and shells	2,080
Brown sand	2,085
Sand and slate	2,090
Brown sand	2,095
Light slate	2,115
Slate and sand	2,120
Slate and sand	2,130
Slate	2,140
Slate and sand	2,168
Light slate	2,175
Slate	2,180
Slate and sand	2,188
Slate	2,195
Light slate	2,210
Dark slate	2,237
Light slate	2,285
Dark slate	2,325
Light slate	2,405
Slate and sand	2,416
Slate	2,485
Slate and sand	2,495
Slate	2,610
Soft slate	2,665
Slate	2,720
Slate and shells	2,730
Slate	2,845
Black slate	2,940

Thickness of Ohio shale penetrated in the well 1,259.

A well drilled at Belpre in 1886 found the Berea grit 67 feet thick, with 4 feet of gray shale in the middle. The stratum was reached at 1,538 feet, or 1,407 below the Pittsburgh coal. Another sand-rock, 10 feet thick, is reported at a depth of 1,740 feet. This would be near the place of the Gordon sand of Pennsylvania.

G. Deep Wells of Trumbull, Mahoning, Columbiana and Belmont Counties.

The deep drilling done in Berea grit territory in parts of the state not yet reviewed will be described in the present section. The counties named above constitute, with Jefferson, a belt upon the eastern border of the state, but the wells of Jefferson county have already been described in another connection.

Niles.

In Trumbull county, quite a large amount of drilling has been done outside of the Mecca Field, but no wells, so far as is known, have been sunk to great depths. At Niles a large volume of gas was struck in 1861, in a well drilled for oil on the Ward property, within the limits of the town. According to tradition the flow was reached at 640 feet in depth. The gas is said to have burned in a flame sixty feet high, but inasmuch as the well was presently sunk deeper, it seems fair to conclude that the supply was derived from a blower in the shale, and not from any sandstone reservoir. The well was drilled to 900 feet, but soon became choked, and the gas mainly disappeared, owing, it is said, to the mismanagement of the well. Another well was subsequently drilled in the same vicinity to a depth of 780 feet, where it was abandoned on account of the tools becoming fast. The gas found at 640 feet, in well No. 1, came from considerably below the Berea grit, which should be found here at not more than 200 feet below the surface.

Oil is reported to have been recently struck on the south side of the county in a shallow well drilled to the Mecca horizon. The occurrence of oil at Mecca is not clearly explained, it is true, but it would be surprising if Mecca should be found to be the only locality in the region where such accumulation has taken place. The discovery of other fields of the same general character, in other words, is rather to be expected. At least such discovery can occasion no surprise. No persistent high-pressure gas has yet been found in Trumbull county.

Youngstown.

In Mahoning county an expensive and persistent search for natural gas has been maintained since the value of the new fuel in iron-working was first made apparent. The Wick Brothers drilled, in 1875, at their Valley Mill, in Youngstown, to a depth of 2,480 feet, the last eighty feet of the drilling being in black slate. The top of the great shale series was struck at about 200 feet, and consequently the interval between the Berea grit and the Devonian limestone in this region, or in other words, the interval occupied by the shales, must exceed 2,280 feet. These figures correspond with all others obtained from the same series on the eastern border of Ohio. The entire interval has not, in fact, been measured here as yet.

Within the last year several other attempts have been made to find gas near Youngstown. A well was drilled by the Furnace Company at Haselton in the summer of 1886, the record of which is given herewith:

Drift..... 60 feet.
Shales, soft, gray, blue flag, shelly rock, gray shale, black shale..... 146 "
Sand at 206 feet, and continuing 160 feet, with a thin bed of shale interstratified about half-way down.

When the horizon of the well-head is considered, the record above given needs no interpretation. The Cuyahoga and Berea shales make the 146 feet of bed rock reached first below the drift. The Berea has an unusual thickness here, as compared with its measures to the northwestward, but it is taking a phase that is persistent to the eastward. We find few measurements in this direction of less than 75 or 100 feet, and it is not uncommon to get twice these amounts in a section.

Gas was found in the Cuyahoga shale in small quantity at several horizons, viz., at 152, 191 and 230 feet. The last came from the Berea grit, and the volume was respectable, but unfortunately salt-water was unlocked with the gas, and it was found impossible to separate these incongruous elements. Consequently, no value was developed by the drilling, but it is to be noted with surprise that the drill was allowed to stop, for once, when the only horizon of promise was passed. It is very rarely that judgment can be brought to bear in a problem of this kind. The temptation to sink further when the gas or oil-rock are found unproductive, especially if they are reached at shallow depths, is generally too strong to be resisted.

During the same year Messrs. George M. McKelvey and Company drilled a deep well on the Reywight farm, three miles southwest of Youngstown. The drilling was carried on under the direction of Mr. C. B. Brainard, who has furnished an excellent record well supported by samples of drillings to the Survey. It is as follows:

Drift			84 feet.
Slate			6 "
Sand-rock (Sharon Conglomerate)			146 "
Slate, black at bottom (Cuyahoga and Berea)			199 "
Hard rock	25 feet.	Berea grit	150 "
Slate	52 "		
Sharp sandstone	73 "		
Gas was found at			435, 448 and 512 "
Salt-water at			537 "

The shale that overlies the twenty-five feet of hard rock is distinctly black shale, and is counted the Berea shale. The fifty-two feet of shale that is represented as interpolated in the Berea grit in the table above is a blue shale of ordinary character. Another division of the elements is possible, viz., the reference of the hard rock and slate to Cuyahoga, and the placing of the seventy-three feet of sharp sand alone under the head of the Berea grit, but the great thickness apparently found for the Berea in the preceding record, together with the facts noted above, lead to the present assignment. The great shale series begins in the well at 585 feet, and continues with many changes of color to 2,075 feet, where the drill rested. The well is not nearly as deep in the shales, it will be seen, as the Wick Brothers' well drilled in 1875. The drill has penetrated only 1,495 feet of shale in this well, against 2,280 feet in the former. The drillings from 1,900 feet downward are quite calcareous. At the bottom of the well they may almost be styled a poor limestone. The surface of the Berea grit in the McKelvey well was about 628 feet above tide. In the Haselton well it appears to be 669 feet above tide. Neither gas nor oil in quantity deserving mention was obtained from the McKelvey well.

Salem.

In Columbiana county considerable drilling has been going forward for the last twenty-five years, and several important tests of the rocks have recently been made. A well was drilled to the Berea grit in Salem in April, 1886, the record of which is given herewith:

Surface (?)	113 to 113 feet.
Coal	2 to 115 "
Slate	85 to 200 "
Sandstone	25 to 225 "
Slate, reddish	15 to 240 "
Sandstone	12 to 252 "
Slate	12 to 264 "
Sandstone	53 to 317 "
Coal	5 to 322 "
Slate	10 to 332 "
Sandstone, gray	20 to 352 "

Slate	70 to 422 feet.
Sandstone, white	28 to 450 "
Slate, black	102 to 552 "
Slate, light	(?)253 to 805(?)"
Sandstone (Berea) struck at about	810 "

The interpretation of the record is obvious. The Cuyahoga is seen to be about 350 feet thick. The thickness of the Berea is not stated, but it is small. It yielded neither gas nor oil. The well was drilled considerably deeper without results.

New Lisbon.

At New Lisbon there are salt-works that have been in operation for a number of years. To obtain a supply of brine for these works, several wells have been sunk to the Conglomerate, which has proved to be the source of salt-water for this region. More recently, deep-wells have been drilled with reference to gas-production. In this search the Berea grit and Ohio shale have both been tested. One well was sunk, in 1885, to a depth of 1,370 feet, the record of which shows the Berea grit to have been found at a depth of 556 feet below the level of the valley, or about 323 feet below tide-water. Gas was found in the lower division of the Berea grit, at a depth of about 600 feet from the surface. The record of this well has been given on a preceding page (page 322).

Another record from the same locality shows the gas-sand to have been struck at 610 feet, and to have been passed at 628 feet. This well was sunk to 1,350 feet. Below the gas rock the order is as follows:

Slate	10 feet.
Salt-water sand, soft	20 "
Slate	70 "
Red rock	90 "
Slate, to the bottom of the well	532 "

This seems to be about the normal section in Columbiana county. It can be generalized thus:

Cuyahoga shale	300
Berea shale	25
Berea grit, often separated into two or more sheets	40 to 150
Bedford shale, blue	70
Bedford shale, red	70

Martin's Ferry.

Gas has been found in moderate volume in some of the later wells of New Lisbon, and the work of exploration is still going forward.

Jefferson county comes next in the line, but its search for gas has

already been described (page 330). It only remains, then, to give a brief account of the deep drilling in Belmont county within the last few years. Numerous wells have been drilled through all this portion of the Ohio Valley, and notably at Martin's Ferry and Bellaire. None of these wells have been successful. The record of the Laughlin well, at Martin's Ferry, as furnished by Mr. J. C. Weston, the contractor, is given below:

	Depth.	Thickness.
Black slate	240 feet.	50 feet.
Gray sand	290 "	50 "
White sand	340 "	60 "
Black slate	400 "	12 "
Gray sand and first gas, salt-water	412 "	14 "
Coal, impure	426 "	12 "
Shell, salt-water and gas	438 "	7 "
Shale	445 "	25 "
Shell	450 "	5 "
Coal, good	480 "	5 "
White sand	485 "	145 "
Black slate	630 "	20 "
White slate	650 "	10 "
White sand	660 "	170 "
Dark-gray sand, cased at 830	830 "	10 "
Limestone	845 "	485 "
Sand, oil and gas at 985	855 "	280 "
Black shale	1,135 "	130 "
Sand shell	1,265 "	12 "
Black slate	1,277 "	253 "
Black sand	1,530 "	130 "
Slate and shells	1,590 "	65 "
Red rock	1,610 "	20 "
Black slate	1,635 "	25 "
Slate and shells	1,645 "	10 "
Shell	1,645 "	10 "
Blue sand	1,650 "	8 "
Red rock	1,660 "	10 "
Black slate	1,670 "	10 "
Shell	1,675 "	5 "
Black slate	2,096 "	421 "
Shell	2,136 "	10 "
Black slate	2,300 "	164 "

The record can be interpreted with but little difficulty, the Sub-Carboniferous limestone, which was found at a depth of 845 feet, proving a great help in this work of classification. It thus appears that the Coal Measures in their several divisions extend to 845 feet, the Conglomerate sandstone of this system being represented in the 170 feet of white sand included between 160 and 830 feet. The Logan sandstone and Conglomerate, which is the salt-water sand of Ohio, is seen in full thickness, is the 280 feet of rock that extend from 855 to 1,135 feet. The

Cuyahoga shale, split in two sections, as is often the case, by interstratified sandy belts, is shown in the two belts of black shale of 130 and 253 feet (123 in the record) respectively, that come in below 1,135 feet. (The record is seen to be erroneous in the enumeration of the element of the shale, and is amended so as to make the figures harmonious). The Berea shale is included in the black shale, by which the Cuyahoga is described. The Berea grit is the 130 feet of black sand that comes next below. The Bedford shale is seen in the sixty-five feet of slate and shells that underlie it, and in the twenty feet of red rock that appear next in the record. The alternations that follow to 2,300 feet are rather more numerous and varied than is common in the Ohio shale to the northward, but taken as a whole, the series is unmistakable, 620 feet of the 673 feet in this interval being referred by the driller to black shale.

Bellaire.

The Wallace well was drilled in 1885, two miles above Bellaire. A skeleton section of it is as follows:

	Depth.	Thickness.
White sand	500 feet.	25 feet.
White sand with salt-water	700 "	35 "
White sand with large amount of salt-water	820 "	360 "
Bottom of great sand	1,180 "	
Interval composed of slate, shells and sand	450 "	
The Wellsburg sand-rock or Berea grit	1,550 "	

A small amount of gas was produced by the rock, but for all large uses the well was a failure.

A well was drilled soon afterward below the town to a depth of 2,700 feet. There was no sand-rock found below 1,650 feet, but the statement is made by the driller, that from 1,900 feet downwards, bands of red shale occurred, 50 to 60 feet in thickness. A similar section is reported from the same depth in a well back of Wheeling.

CONCLUSION.

The counties of the state in which the Berea grit constitutes an element in the geological scale, have now been passed in review, and the results of recent drilling in them have been placed on record, with the following exceptions, viz.: Geauga, Portage, Carroll, Harrison, Monroe and Pike. In all of these, excepting the last, the omission from the previous records results, not necessarily from failure on their part to make the tests, but rather from the failure on the part of the Survey to obtain the facts developed by the drilling done in them. As far as known, the results are, in no respects, more favorable than in the

counties already reported. There is nothing in them to break the record of failure that fills the preceding pages.

It is quite likely that some of these counties, especially Harrison and Monroe, deserve to be tested still further in respect to gas and oil supplies. It is believed that light folds of the strata traverse one or both of them, on which some probability, or at least possibility, of production might well enough be based.

The accounts that have been given do not, by any means, exhaust the list of the tests that have been made in eastern Ohio during the last three years. The reports thus far presented are designed to be representative, rather than complete. As far as possible, the experimental drilling of the leading towns has been reported. Scores, and, perhaps, hundreds of wells have been passed without notice in this account, but while every record, if carefully studied, will doubtless furnish new and interesting facts, it is not likely that any large results have been missed.

The facts that have now been presented are undeniably discouraging as to the presence of valuable, and, at the same time, wide-spread accumulations of gas and oil throughout central Ohio.

The main reliance of this part of the state must be placed on the Berea grit, as has been already demonstrated, and this stratum has failed, in the large way, to meet the demand that has been thus placed upon it.

It is nowhere wanting in the source of gas. A supply adequate to all demands is to be found in the great series of Ohio shales, 500 to 2,500 feet in thickness, which everywhere underlie the Berea grit. Neither does this stratum lack the porosity which is essential to the storage in it of gas and oil. It is, however, often thin, and sometimes it becomes too fine-grained or close, to serve a good purpose as a reservoir. The general porosity of the rock is, however, abundantly attested by the presence of salt-water in it to so large an extent. Again, the Berea grit never lacks the good cover necessary to oil and gas production. The shale series overlying it meets all demands in this respect. What, then, is wanting to make the series a source of large production? The answer is brief. It lacks proper structural conditions. The series of strata within which it is included is found to be wanting in due relief. The Berea grit descends uniformly from its outcrops to its deepest stations in the state, and in this prolonged slope there are no such interruptions as are necessary to the accumulation of oil and gas. Some arches and terraces there are, but they are overrun by salt-water very soon after they are penetrated by the drill.

What, then, are the prospects of eastern Ohio for natural gas? There is no mistaking the answer given by the drill. It has been constantly

kept at work for the last three years. A geological survey, of a very expensive sort, has been in progress. At the lowest calculation, $500,000 have been spent upon it in eastern Ohio since 1884. With what result? Aside from the Macksburg field, the returns for all this outlay are insignificant. For far the larger number of instances there is nothing whatever, to be placed to the credit side of the account.

What has been will be. The discovery at any time of small productive fields, like Macksburg, within the large territory now under consideration, should occasion no surprise. Such discoveries are, in fact, to be expected. But the ground has already been so widely tested, that it is safe to say that such discoveries must be confined within quite narrow limits. It does not seem probable that any of these productive tracts lie within easy striking distance of the towns and cities that so greatly need and desire an abundant supply of natural gas.

A few statements need to be made in regard to the composition of the gas from the Berea grit.

On page 135, the analyses of Pittsburgh gas made by Mr. S. A. Ford, are given and discussed. The remarkable character of the analyses was noted, but not questioned. It was supposed that so anomalous and surprising results would not have been published unless they had been established beyond all question. This conclusion has proved to have been a mistaken one.

The subject of the composition of natural gas from the various horizons of western Pennsylvania, has been more recently investigated by Professor Francis C. Phillips, of the Western University, Allegheny, for the Geological Survey of Pennsylvania. This report has been published in the *American Manufacturer*, in advance of the Annual Report of the Survey, and has thus become available for use. The investigation appears to have been carried on in accordance with the best methods known to science, and the report bears upon its face the marks of the most scrupulous care and the most conscientious painstaking.

The anomalous features of the results before announced all disappear, and Pittsburgh gas is seen to be a steady and self-consistent product. It agrees, very closely, in composition with Findlay gas, as determined by Professor Howard, two years since. Both contain about 90 per cent. of hydro-carbons. The main difference is in the presence of a small amount of sulphuretted hydrogen in one, and its absence from the other. The subject cannot be further discussed here, but we are sure that the gas of the Berea grit, and, also, of the underlying shales in Ohio, will show the same general constitution that is reported by Professor Phillips, from western Pennsylvania. A few of his analyses are herewith given. In them we see, for the first time, the true constitution of the

natural gas of the most famous fields of the country. The analysis of the shale gas of Fredonia, N. Y., is added to the list:

Constituents.	Sheffield.	Kane.	Wilcox.	Lyon's Run (Murrysville).	Fredonia, N. Y.
Nitrogen	9.06	9.79	9.41	2.02	9.54
Carbon dioxide	0 30	0 20	0.21	0.28	0.41
Hydrogen	0.00	0 00	0.00	0.00	0.00
Oxygen	Trace.	Trace.	Trace.	Trace.	Trace.
Sulphuretted hydrogen	0.00	0.00	0 00	0.00	0.00
Paraffins	90.64	90.01	90.38	97.30	90.05

CHAPTER V.

THE OHIO SHALE AS A SOURCE OF OIL AND GAS IN OHIO.

By Edward Orton.

The most widely extended and the best known source of natural gas in the state, but not the most valuable, remains to be considered, viz., the Ohio shale. This complex formation has already been described at some length in Chapter I, and frequent reference to it has been necessary in the chapter on the Berea grit.

There are two main areas of the Ohio shale in the state, the principal one entering from the east along the shore of Lake Erie, and forming the border of the lake as far west as Sandusky, with a breadth varying from ten to thirty miles. From Sandusky the formation stretches southward with about the same breadth of outcrop as already described in a direction slightly west of south, to the Ohio Valley. The two areas occupy four or five counties, in whole or in part, in the extreme northwestern corner of the state, but these counties are heavily covered with drift, and consequently but little is known of the underlying shale formation, and its influence upon the surface is reduced to a minimum. There is a third small area in Logan county, occupying the highest land of the state. There are, of course, numerous outliers, small and great, along the western margin of the largest area, which are counted with it. All of these are shown on the accompanying sketch map.

The first of these divisions, whose northern and western edges have now been traced, is co-extensive, in outcrop and under cover, with the limits of eastern Ohio, and indeed it stretches far beyond these boundaries into adjacent states.

The shale formation is thinnest to the southwestward. In Highland and Adams counties, included sections are found which do not exceed 250 feet in thickness. In Ross and Pike counties, the measure becomes a hundred feet greater, and still further to the eastward a rapid expansion is found. These facts are illustrated, in part, in the section of the preceeding chapter in which the rocks between Columbus

LAKE ERIE
WILLIAMS
FULTON
LUCAS
DEFIANCE
HENRY
PAULDING
SENECA
HURON
ERIE
LORAIN
CUYAHOGA
GEAUGA
ASHTABULA
TRUMBULL
PORTAGE
SUMMIT
MEDINA
WAYNE
RICHLAND
ASHLAND
CRAWFORD
MARION
MORROW
KNOX
DELAWARE
LICKING
FRANKLIN
PICKAWAY
FAIRFIELD
FAYETTE
HOCKING
VINTON
JACKSON
ROSS
PIKE
ADAMS
SCIOTO
LAWRENCE
HIGHLAND
BROWN
Cleveland
Toledo
Sandusky
Mansfield
Wooster
Akron
Ravenna
Warren
Jefferson
Steubenville
Bellaire
Marietta
Pomeroy
Cincinnati
Portsmouth
Ironton
MAP OF THE TERRITORY
IN WHICH
LOW PRESSURE GAS
FROM THE
OHIO SHALE
IS DUE
EXPLANATION
Ohio Shale
1. In outcrop.
2. Under not more than 300' of cover
M. R. Campbell del.

and Bellaire are represented. The series gains somewhat in volume also to the southward, but in the first included sections east of the limestone belt in northern Ohio, it is not more than 600 to 800 feet thick. What the volume of the shales originally was in northwestern Ohio, it is impossible to say. We do not now find more than 200 feet of the shales in any of the sections that remain, but it must be borne in mind that this quarter of Ohio has been especially exposed to glacial denudation, and that this formation in particular has little resisting power. The enormous quantity of the shale that is found in the bowlder clay that covers the western half of the state in particular, illustrates in a striking manner the great amount of waste which the shales have suffered from this agency.

From the eastern border of the limestones the shales thicken very rapidly to the east and southeast. This is represented in the section from Elyria to Akron which appears in the preceeding chapter, page 338.

The limestone is seen to descend to the southeast, while the Berea grit inclines in the opposite direction.

The interval between the Berea grit and the Upper Helderberg limestone at Elyria is 800 feet, while at Akron the same interval is 1,862 feet. This important feature in the structure of this part of the state has already been discussed in Chapter I, under the head of the Akron axis, page 57, but the fact to be noted here is the rapid increase of the shales in a southeasterly direction. The interval between the horizons named above at other points in the state are given below. The points along the western margin where the measurements are smallest are named in the first column, but even here there are some localities as Mt. Vernon, that are far removed from the margin of the formation.

Intervals between Berea grit and Upper Helderberg Limestone.

Elyria	800	feet.	Lancaster	630	feet.
Wellington	920	"	Marshall, Highland county	250	"
Plymouth	648	"	Berea	1,250	"
Crestline	508	"	Cleveland	1,400	"
Shelby	657	"	Akron	1,862	"
Wooster	1,345	"	Massillon	1,860	"
Mansfield	640	"	Canal Dover, exceeds	1,870	"
Mt. Vernon	867	"	East Liverpool exceeds	2,400	"
Newark	890	"	Wellsville, exceeds	2,600	"

From central Ohio eastward the drill has never gone deep enough to find the bottom of the Ohio shales. In Washington county, as has been shown in the record of the Rake well, at 1,259 feet below the Macksburg sand, the drill was still in unbroken shale. It is probable we need to go down at least 1,200 feet further to find the limestone floor.

The limestone has been reached at various points on the shore of

Lake Erie, among which may be named Elyria, Cleveland, Erie and North East, Pennsylvania, and Fredonia, New York. It rises to the surface again near Buffalo.

The thickness of the shale is seen, from the statements here given, to be altogether a question of geography. On the western border of the main area it ranges from 250 to 650 feet in thickness, while to the east and south it strengthens, rapidly reaching a total of 1,200, 1,800, 2,400, and even 2,600 feet, and in the two last cases, which are in the Ohio Valley, the series is still unexhausted.

The composition of the series, so far as the alternating bands of black, gray, blue and greenish-blue shales are concerned, has already been described in Chapter I, and it will be much more fully illustrated in the well records to be given in the various parts of the field.

Source of Shale, Oil and Gas.

The shales in themselves considered are but small producers of oil. Not a single shale well is known, the supply of which is derived exclusively from the shale, that has ever produced more than ten or fifteen barrels of oil in a day, and even such yields have been limited to very few days at most. Where interrupted by sandstones, however, or even by sandy shales that are buried in them, all may be changed. Such sandstones are likely to become oil-sands, and to constitute the great reservoirs from which almost fabulous amounts of oil and gas flow forth when these reservoirs are reached by the drill. Although no great accumulations of oil are found in the shales proper, it would be wrong to infer that they are poor in petroleum. On the contrary, they contain much more than any other of the strata with which they are associated, the great sandstone reservoirs not excepted, but it is in a distributed condition that the petroleum occurs. The entire body of the shale carries a determinable percentage. The percentage is small, but the aggregate is vastly larger to the square mile than any square mile of the most prolific oil-field has ever yielded to the drill. Professor N. W. Lord, Chemist of the Survey, determined the amount of petroleum existing as such in normal samples of Ohio black shale. He found the amount to be slightly less than one-fifth of one per cent., but he learned from his investigations that the finer the division of the shale, the larger was the percentage of oil obtained. It was therefore certain that the true percentage exceeded that reported; further than this, there had, undoubtedly, been some loss of petroleum from the exposure of the shale, but even on the percentage obtained, if the shale series is counted at the low average thickness of 1,000 feet for its entire area, the total

amount per square mile passes far beyond the limits of clear comprehension.

Calculations show that it would exceed ten million barrels (10,000,000) to the square mile, and such figures stand, of course, merely for numbers that turn up in arithmetical processes, but to which we are unable to attach any definite significance further than to recognize in them very large numbers.

The oil-stock of the shales is large, as thus appears, but the oil-production is very small. The case, however, stands somewhat better with regard to gas. Here again the lack of sandstone reservoirs forbids large accumulations, but the shales themselves yield gas in such volume as to become of considerable economic importance. There can be no question but that gas is derived directly from the oil of the shales. Deep as the drill goes down the shales are found charged to the extent noted above with petroleum, which begins to break up at once into volatile compounds when exposed to the air.

Surface Indications.

Both oil and gas, as thus described, are found rising slowly through the shales to the surface at multitudes of the outcrops of this formation. No doubt most of the outcrops have been thus distinguished at some time in their history, but at many points the accessible stocks have been so reduced as to be no longer conspicuous or even noticeable. The movement of the oil to the surface is probably the result of a slow circulation in the shales, gravity bringing the oil upward as water descends. When the oil and gas appear in this way, the oil as a thin film over the water that escapes, and the gas issuing from the seams and joints of the shales, sometimes in bubbles through the water, and sometimes in small but steady streams, they are called surface indications, and great account is made of them in the search for oil and gas.

At many points such indications have been found to be the forerunners of the largest production of oil and gas. The Findlay field, for example, always abounded in these evidences of a great stock of gas buried beneath the surface, but it was a long while before any one was prepared to interpret these indications in the ordinary way.

The surface indications of the Ohio shale stand for no large accumulations, but they are constantly interpreted, or rather misinterpreted, as if they did. Such escape as is here described is the normal condition of the shales. It testifies to the distributed stocks of petroleum that lie below and that are absolutely universal. They are found wherever the shales are found. The main outcrops of the shales are not less than 400 miles

in length in Ohio, and there are but few miles of these outcrops except where drift deposits interfere, in which oil films and gas bubbles cannot be found. Since natural gas has begun to attract such general attention these surface indications are constantly being rediscovered, and a week does not pass without the published announcement of the sure presence of abundant stocks of gas along these shale outcrops, amply sufficient for entire districts of the state, but when the drill descends at the most promising of these points it releases but a weak supply, adapted in its best condition only for domestic use on a very small scale.

Several hundred wells have already been drilled in various parts of the state in the shale formation, and the conclusions drawn from so large a number of examples are not at all likely to be set aside by any experience that is yet to be obtained. We know both the quality and the quantity of the bituminous products that the shales are able to supply.

Character of Shale Gas.

The gas yielded by the Ohio shale is definitely characterized. It is low-pressure gas—in other words, it does not attain the high-pressure of the great wells which are used for large public supply. This is the same as saying that it never produces a large daily volume of gas; but terms like these are relative. What is high-pressure, and what is a large daily production of gas? The Findlay wells reach a closed pressure of a little less than 400 pounds per square inch. The great wells of Pennsylvania show pressure much in excess of the Findlay wells, reaching, according to good authority, a pressure of at least 650 pounds per square inch. Pressures much greater than this are reported.

In contrast with these fields the closed pressure of shale gas-wells has rarely been known to rise beyond 100 pounds to the square inch. In almost all the cases noted, the pressure has remained much below 100 pounds. What are called good wells show a maximum of fifty, sixty, or seventy pounds.

Again, the maximum production of the wells of the Findlay gas-field is 15,000,000 cubic feet per day. Wells are not counted of much force or value, the daily output of which does not exceed one-half million cubic feet. The great gas-wells of western Pennsylvania exceed the largest production of the Ohio field by several million cubic feet.

In contrast with this no shale gas-wells have been measured that produced more than 100,000 cubic feet per day, and it is very rare for them to reach this figure. They are counted excellent wells when they reach 50,000 cubic feet per day. What is meant by relatively low-press-

ure and small production in shale gas-wells, appears from the facts and comparisons here given.

The composition of the shale gas proper has not been determined by the Survey, but it is doubtless identical with the gas found in the Berea grit. An analysis of the latter, from the Neff wells, made several years since by Professor E. W. Morley, of Western Reserve University, is given below:

Specific gravity	.65
Oxygen	.80
CO_2	.30
CO	.50
Marsh gas	81.40
Ethyl hydride	12.20
Nitrogen	4.8

The analyses recently made of natural gas in the Pennsylvania fields, and published on page 409, can be compared with these results. They will be found to agree fairly well. The marsh gas and ethyl hydride reported here can be counted together as paraffins and the total amount is seen to be 93.60 per cent.

The stocks of gas derived from the shale, although moderate or small in amount, are quite persistent, and therefore valuable. No gas supply is known that is more enduring than the supply derived from the shales. Natural gas of this description rises, in many cases, with the water of springs, and from all that we can see, it is as persistent as the water which it accompanies. The gas springs of Fredonia, New York, have been known since the country was first occupied, and the gas produced by them has been utilized in the town for lighting purposes since 1821. Wells have been drilled by the side of the original springs, and have interfered with the latter to some extent, but the flow still continues from the old sources. From wells drilled into the shales expressly for gas to be utilized as light, heat, or power, we cannot obtain any decisive testimony as to their durability, from the fact that they are all of comparatively recent date, but so far as it goes, the experience derived from them is quite satisfactory and assuring. Wells drilled fifty years ago are still fairly productive. In some cases they have been furnishing a steady supply since they were drilled, without requiring a dollar of outlay during the entire interval. The production is probably gradually diminishing in most cases, but enough is generally left to enable the wells to do all that is expected of them.

The two facts named above, namely, the low-pressure of the shale gas, and its persistency, point out in very clear light its special adapta-

tion. It is, by way of excellence, a household fuel, and but little beyond this should be expected or asked of it. As a source of light, it is somewhat less satisfactory, as the percentage of illuminating agents in it is small, but for heating purposes it is in every way admirably adapted. It is equally valuable for stoves, ranges, grates, and steam production on a small scale. In many houses supplied with gas the kitchen fire never goes out. The convenience resulting from its introduction into household use is inexpressible, and a surprising reduction in the labors of housekeeping is effected by it. There is no greater luxury in the modern house than gaseous fuel.

The light arising from the burning of the gas is blue and feeble, but the heat is intense. A simple method of enriching the flame in grate fires, supplied with the gas, was accidentally discovered by Mr. George H. Ely, of Elyria, a short time since. By sprinkling, from time to time, a small quantity of common salt over the fire-brick or fire logs, the bright yellow flame of sodium is communicated to the gas. The salt makes a glaze upon the brick and the effect lasts for some time. The gas fire is made much more enjoyable when a bright and cheerful light is added to its other advantages.

The use of this low-pressure gas is accompanied with little of the danger that has been encountered in bringing high-pressure gas into cities and towns. Experience is teaching us how to reduce this danger to a minimum, it is true, but in the case of shale gas-wells the danger never existed.

For manufacturing purposes on any considerable scale the shale gas is scarcely applicable. There is too little of it. There are comparatively few wells of this group that produce 50,000 cubic feet per day, but without at least this amount, a well can scarcely be expected to supply steam for a fifty-horse-power engine. Such an amount of gas is doubtless enough for several such engines, if it could be applied at the well's mouth, and with the assurance that proper economy in its use would be secured, but in all such cases it is always desirable to leave an untaxed supply of production, and upon this ground the statement above given is justified.

A like inadequacy is usually found in the shale gas-wells for the supply of gas for villages or towns. It has not the force requisite to carry it through long lines of pipe and maintain a vigorous supply at their termination. It is quantity again that is at fault. The details given in the subsequent portions of this chapter will fully illustrate these statements.

It is not only domestic supply that the shale gas is specially fitted to furnish, but it is *individual* household supply for which it is likely to

be most valued in time to come. Those who own farms or even village or city lots within the productive areas of the shale gas-field—and so far as is now known a very large percentage of the shale territory is productive on the scale already noted—will come to value their lands for the gaseous fuel which they hold in store as much, or perhaps more, than they would value the same lands if supplied with wood lots or coal mines. Farm houses within these limits will be arranged, in coming time, for the use of natural gas, and a hundred-acre farm will be found to have great possibilities in this respect. If a single well will last a score of years, such a farm will contain an available supply for many centuries. The initial expense of piping a house and drilling a well seems burdensome, but these items can be reduced by good management to low figures, and there is no doubt that a wise economy will justify the expenditures. Wells can be drilled in the shales at the rate of 150 to 200 feet per day. The interest on the investment will be much less than the ordinary fuel account of a year, let alone all the other great advantages to be derived from the use of gas. It must be borne in mind that a well yielding but 1,000 cubic feet per day, or even less, if attached to but a single residence, can make itself very serviceable. There would be at almost all times a "head" of pressure upon the well arising from accumulation during the intervals in which the gas is left unused. An ordinary stove does not actually consume more than twenty-five to fifty feet of gas per hour, so that several stoves could be supplied by a well of very moderate capacity. The most of the chances for measurement in the case of the shale gas-wells have been obtained when the wells were recently drilled and while at their best. Wherever measurement has been applied to wells that have been in use for several years, the production has been found to be small, not exceeding one or two thousand feet per day. The largest production of any shale well measured has not exceeded 100,000 cubic feet per day.

There is a mode of estimating the capacity of these shale gas-wells in northeastern Ohio that may be mentioned in this connection. Every pound of pressure when the well is shut in is counted equal to a production of 1,500 feet of gas per day. The method is supposed to be established on practical tests, but it is certainly unsound. The facts from a single well have, no doubt, given such results, but there is nothing to warrant the conclusion that the same relations will be found in other wells. In fact, direct measurements show that the claim is entirely untenable. Still, it is true that the shale gas-wells of a district are more nearly alike than high-pressure wells, and it may be that calculations on this basis will not be very far from the truth for a single district so long, at least, as the entire closed pressure is confined to a few

pounds. Even this reduced claim has no authority whatever. The proper instrument for measuring the flow of these low-pressure wells is the anemometer. Its use for this purpose was first suggested by E. McMillin, Esq., of Columbus.

Structure as Related to Shale Gas Wells.

In the production of oil and gas, and especially of the latter, from both the Trenton limestone and the Berea grit, the elements of structure, that is, of the arrangement of the strata, including the folds, fractures, and dips by which they are affected, have been found to be of paramount importance. Is this factor equally influential in determining the gas production of wells sunk into the shales? There are some reasons why it might not seem to be equally important in this latter field. For example, no reservoirs on a large scale are found in the shales, and inasmuch as the principal effects of structure seem to be exerted on this element of oil and gas production in differentiating gas, oil, and salt-water in the rocks, it appears probable that wells in the shales are not so entirely dependent on and conditioned by this factor. A well drilled into a mass of rock throughout which gas is everywhere distributed, and from which water is excluded, would yield, at least, a small supply under any circumstances and without special regard to the facts of structure. But it is probable that such supplies would be very limited, and wells drilled under these conditions would be practically failures. On the other hand, it is obvious that in rocks as compact and close-grained as the shales of the Ohio system, the passage of gas would be very much facilitated by any crevices that are open in the shales, and along every minor axis of elevation we should have the right to look for the largest supply of gas. It seems probable that slight disturbances which would be inadequate to secure concentration in the great gas-bearing rocks, are much more effective here, or in other words, that crazed or broken structure is all that is required. This latter view was clearly brought out by Newberry many years ago in his discussions on this subject. Structure is, therefore, in all probability, even more effective in the shales than in the sandstones and limestones, because so much lighter phases of it can be turned to account in the way of furnishing wells with gas, but the special phases of it on which high-pressure gas is dependent are not required in this field.

The difficulty or impossibility of marking and following horizons in the shales has already been pointed out. We can scarcely go beyond the portions of the rock that are uncovered in the beds of streams and other such situations in our recognition of lines of uplift. When the beds are covered by drift, or even by soil, we have thus far found no

clues whatever. It is quite possible that persistent beds will come to be recognized when study enough has been given to the formation, from which the facts of structure may be made out independent of exposures, but up to the present time few such horizons have been found.

The leakage of the shales, which has already been spoken of under the head of "surface indications," generally escapes through the joints of the rocks, at least where the exposures are such that the facts can be made out. In some cases there are faint but distinct axes of elevation that can be traced for several hundred feet, occasionally, and these are outlets for gas along their whole extent. In the bed of Rocky River, four miles below Berea, near the residence of H. A. Mastick, Esq., such an axis was found, bearing N. 40° E. A rise of but eight feet is visible in the beds that are uncovered here, but gas, accompanied with salt-water, has been found escaping since the country was first occupied. A well recently drilled on this line of uplift, obtained a fairly vigorous supply.

The moderate success of so large a number of wells covering so considerable a scope of country, through town after town and county after county along the shore of Lake Erie, is sufficient proof that these wells are dependent on no large structural features. The only explanation of such production that would be possible, if such features were counted essential, would be the presence of a broad and low anticlinal, parallel to the shore of the lake. Of the existence of such a fold it is scarcely necessary to say we have no proof. There is, in fact, no room for these large structural features in the country traversed, that is, the frequent natural exposures of the rocks are seen to be destitute of all important arches and folds. The minor rolls and light disturbances, such as the shales everywhere show in exposed sections, are probably sufficient to account for the facts of production. The great differences of production, and the occasional failures that occur, must also be borne in mind as we consider these facts. The points last-named can be rationally connected with the minor points of structure already described, or with the absence of such facts. We conclude, therefore, that structure, in its less pronounced phases, is probably essential to the gas production of the shales, but that the great features upon which the accumulation of the reservoir wells depends are not needed here.

Areas of Shale Gas Territory.

The territory in which gas of the character described above is to be found in Ohio can readily be pointed out. The northern and western outcrops of the great shale formation, in the eastern and central parts of

the state, constitute its outer boundary. Passing southward and westward from this boundary, the shale gas territory is, without question, co-extensive with the shale formation. It does not, however, stop at this limit, but it takes in also nearly as great a breadth of the Waverly formation, in addition, as has been already assigned to it. No high-pressure gas is found in the Waverly until the Berea grit has taken at least 400 to 500 feet of cover. We must add, therefore, to the shale formation as much of the adjoining Waverly border as is necessary to carry the Berea grit to an average depth of about 300 feet below the surface, and we thus obtain a belt fifteen to thirty miles wide that can be followed continuously from the Pennsylvania border to the Ohio Valley and beyond. This is by way of excellence the area of low-pressure gas in Ohio. It is shown on the map that accompanies this chapter.

A second area, but of less importance, is found in a few of the northwestern counties of Ohio. The Ohio shale, as will be remembered, constitutes the surface rock in the whole, or in parts of Lucas, Fulton, Henry, Williams and Defiance counties. It is, however, deeply covered with drift deposits through most of this area, so that it has but few outcrops, and moreover, it was so reduced by glacial agencies before the drift was deposited upon it that there are, at most, but a few hundred feet of the shales to be found in any section. It has not exceeded 200 feet in the wells that have thus far been drilled within this general area.

Within the areas thus indicated, a large amount of exploration has been and is still being carried on. A part of this exploration and its results have been described in Chapter IV, in which various records are given of wells that have been drilled in districts where the Berea grit makes the surface rock, or where it is struck at moderate depths. But there remains a great body of facts drawn from unmistakable shale territory, that is, from regions in which the shales are the surface rocks. The explorations have been so extended that nothing like a full account can be undertaken here. The experience of various towns and localities will be briefly indicated, and from them it will be possible to deduce the general laws that seem to govern the gas production of the formation.

Records of Shale Gas Wells.

A brief review of the results of drilling in the shale belts of the state will here be given. The experience of towns beyond the state line, along the shores of Lake Erie, in seeking supplies of natural gas, is quite widely known. Fredonia, New York, began as far back as 1821, to utilize natural gas derived from springs in the valley that passes through the town. Barcelona, the harbor of Westfield, N. Y., used gas

in the government light-house that was formerly kept there, for thirty years, the gas being derived from similar adjacent springs, and Erie and Northeast, Pennsylvania, have made considerable use of gas for the last fifteen years. There is probably not a town between Silver Creek, New York, and the Ohio state line in which natural gas has not been sought and found within the last dozen years, though often found in very moderate quantity. Erie is, perhaps, better known in this connection than any other town. Its wells are all running low at present, partly, at least, through the access of water from above to the gas-bearing horizons. The water has gradually invaded the shales through neglected wells, and has repressed the gas throughout the whole territory of the town. The experience of other towns in maintaining their supply is more favorable. The same conditions that are found at Erie occur in the entire belt which we find in Ohio. West of the state line, gas-wells are quite as numerous as to the eastward. Here also every township on the lake shore between the state line and the western outcrop of the shales has probably made its trial. If there are any townships in which drilling has not been done, the number is certainly very small. No careful and particular enumeration will be undertaken, but the facts in the several counties will be briefly sketched.

Ashtabula County.

Conneaut.

Within the last two years several wells have been drilled at Conneaut, and in its immediate vicinity for gas, all of which have been more or less successful. Several are reported to have obtained gas supplies from this formation. But drilling began here many years ago. In 1870 a well was drilled for oil at the paper-mills, the record of which has been kindly furnished to the Survey by P. B. Doty, Esq., who is familiar with all the facts. Gas was found all the way down in this well, but no oil, and as gas was entirely unappreciated at the time, the well was counted a failure. Gas appeared bubbling through the water at fifty feet when the well was drilled It increased at frequent intervals as the drill descended, until at 498 feet, a vigorous "blower" was struck, which threw the water out of the well, and is said to have lifted the tools. A second well-marked flow was found at 537 feet; a third, t feet; and still others, at 580, 612, 630, 648, 750 feet. The well was finished at 850 feet. The upper beds of the shale were blue, but all below 200 feet was reported black. It was, however, only a darker shade of blue. A little salt-water was obtained at 630 feet. The well was abandoned for many years, and water was allowed to enter from

above, but the gas was not entirely repressed. It found its way through the water to the surface, and within the last two or three years it has been introduced into the mill, where it serves a small purpose for illumination. The flow, however, at the present time, is not important. A second well, drilled a few rods distant from well No. 1, at a later date, found but little gas. The later experiments have been much more satisfactory because the drilling was now done expressly for gas, and all the conditions were made to favor its production. It is understood that a number of fairly vigorous shale wells are in operation at the present time.

A deep well recently drilled here by the village corporation, found a very strong limestone brine at 1,942 feet, which nearly filled the well.

Kingsville.

A successful well was drilled in North Kingsville in April, 1885, by John H. Titus, at his Plastering Hair Works. The well is only 320 feet deep, but at the date when it was examined, namely, in July, 1885, it was producing a good volume of gas, as will be shown below. Its behaviour since that time, as reported by the present owner, is fairly satisfactory. The well has been entirely neglected for a year and a half, and water has found its way into it from some source, but quite a vigorous flow is still maintained. It is estimated to retain about half of its initial volume.

The record of the well is given below :

Soil	9 feet.
Gas found at	32 "
Well cased at	35 "
Gas for the supply of boiler—struck at	60 "
Gas veins struck at 76, 143, 161, 185, 187, 221, 223, 252, 298, 312, 317, 320 feet.	
Heaviest flow was at	227 "

At 252 feet the shale grew darker, and was called black below this point. A small quantity of salt-water was found at 250 to 300 feet that needs to be pumped out every week or two. When shut off for five minutes the gas increases to a pressure of thirty-two pounds to the square inch. As measured by the anemometer, the production of the well on July 2, 1885, was found to be 37,440 cubic feet per day. The gas renders excellent service in steam production in the factory, and has paid for itself many times over.

At South Kingsville, Mr. Jacob Flickinger drilled a deep well a number of years since, which began and ended in the shales. It was finished at a depth of about 1,200 feet. The series traversed showed the usual alternation of light and dark beds. This well is of special interest, from the fact that it was in drillings obtained from it at a depth of 900

to 1,000 feet, that the first specimens of *Sporangites Huronensis, Dawson*, outside of the original locality in Canada, were obtained. Since their rediscovery at this point, they have been found in black shales in various quarters of the country, and even from two other continents. Gas was struck first in this well at ninety-eight feet. The last vein was found at 372 feet. A small quantity of oil was obtained at 441 feet, just under a ten-inch shell. Thinner shells, or hard layers, from two to six inches in thickness were often found, and invariably in connection with additions of gas or oil. The shale turned dark at 450 feet. At 632 feet, it showed itself to be distinctly petroliferous by its odor, and this character was maintained thereafter. At 695 to 706 feet, a very black band of slate was found, which the drillers took at first to be cannel coal. Blue bands alternated with black shale from 695 feet to the bottom of the well. No important additions of gas were obtained below 372 feet. The supply, though small, is exceedingly useful. It was introduced at once into the house, and serves for a cooking-stove and for heating, to some extent, and for lighting the house throughout, but it is insufficient for the entire supply. All told, it would keep about twenty burners in steady operation.

Ashtabula.

In and around Ashtabula many shale wells have been drilled within the last few years. In November, 1884, Mr. John Manning drilled a well at his residence on Lake street for water, the supply of which, in this part of the town, is very inadequate. Finding no water at or about fifty feet, within which limit he had expected to stop, he concluded to sink deeper in his search. At ninety-seven feet, he struck a small flow of gas. At 176 feet, the amount was considerably increased, and it was forthwith introduced into household use. The well was drilled to a depth of 307 feet. But a single band of black shale was reported by the driller. Several short-lived "blowers" were struck in the descent, but the main supply comes from the horizons already noted. The gas serves for a cooking-stove, one or two heating-stoves, and for all the light that is required in the house, and also for street-lights. Less than half of the gas produced by the well is thought to be used in all these ways. The highest closed-pressure of the well is reported to be eighty pounds to the square inch, but no accurate figures are at hand. The gas maintains a pressure of four or five pounds in ordinary use. Mr. Manning is positive that the flow of the well is greater in warm weather, and especially when the wind is in the south. He reports a range in pressure of one and a half to three pounds, according as conditions vary in this respect. A northeast wind is especially marked, he says, in reduc-

ing the pressure and flow of the well. Opinions like these have been obtained from many quarters, but nothing short of systematic observation can show whether there is a good foundation for this common belief in regard to the relation of gas-production to temperature, and the direction of the wind. The entire cost of drilling and equpping the well is reported by Mr. Manning to be $365.

In December, 1884, Henry H. Hall drilled a well at his residence in Ashtabula for the purpose of securing a home supply of gas. The record of this drilling is as follows: Soil, gravel, etc., 12 feet, followed by blue shale. A good vein of gas was reached at 250 feet, which burned twelve feet high at the casing. By mismanagement of the drilling, as was thought, the well became flooded at this point, and the gas was overpowered. The water was at last withdrawn, but not until the volume of the gas had been permanently reduced. On going deeper, additions to the supply were made from point to point, and at 375 feet a flow was secured that was almost equal to the one that had been lost. The gas continued to come in under the "shells," as they were successively struck, until a depth of 410 feet was reached. No increase of volume came from below this point, and the drill was stopped at 500 feet. Strong brine was found in descending between 400 and 500 feet, but the amount was small. By shutting off the gas for twenty minutes, a pressure of eleven pounds was obtained.

A well was drilled by the Ashtabula Hide and Leather Company two years since, at the tannery in the valley. It is 358 feet deep, and yields a small supply of gas. Gas was reported at nine different horizons as the drill went down. A "blower" of large volume was struck at 290 feet.

Geneva.

The village of Geneva and its vicinity have proved an excellent field for shale gas. Four wells drilled here in 1884 and 1885 showed greater energy than any others along the lake shore. The first of the series was drilled a mile and a half east of the town by A. D. Myers, Esq., for the supply of his residence. This was abundantly successful in its search, and other wells were forthwith undertaken in the town proper. Two wells in the center of the village, belonging respectively to W. H. Munger, Esq., and the Fountain House, came next in order. The former was counted the most vigorous of the series when visited in 1885. Its record is substantially as follows: From 130 to 200 feet, gas enough was obtained to supply a twenty-horse-power boiler. At 165 and also at 260 feet, a little salt-water was found. It occurred in both instances, according to the driller, in the brown sand. It is claimed

that a few quartz pebbles were brought up in the sand pump from this part of the well. The well was cased at 260 feet. A good flow of gas was found at 650 feet, and valuable additions were made to it below. The well was continued to 1,375 feet, the entire depth being gained in seven days' drilling. At the bottom a vein of gas was struck, strong enough to blow large chips to the surface. The shale was called black by the driller, but it scarcely deserves the name. The driller reports a large amount of brown sand in the well, but samples were not at hand for the identification, and the name is probably applied to some particular phase of the shale in this region. The gas shows a steady pressure of eighty-five pounds, and the supply is ample for a number of residences.

The Fountain House well was carried down to a depth of 850 feet. It was cased at 260 feet, above which a considerable flow of salt-water was obtained. At 600 feet a "blower" of gas was struck that lasted for twelve hours. There were two other noteworthy gas horizons, and a steady pressure was maintained in the well. The supply is ample for the use of the hotel, for which the drilling was done.

Other wells of the same general character have since been drilled in Geneva, and the fact is thus thoroughly established that an invaluable stock of buried fuel is easily accessible here.

The record of a single well drilled at Rock Creek, in the central part of the county, will be introduced here. The well was drilled by D. B. Duff and Brother, by whom the record was kindly furnished for the use of the Survey. It is as follows:

Shale, mainly light-colored	867	feet.
Black shale	125	"
Light shale	20	"
Dark shale	18	"
Light shale	28	"
Dark shale	22	"
Light shale	5	"
Dark shale	65	"
Light shale	30	"
Dark shale	95	"
Light shale	121	"

The last general division of the alternating bands, which makes an aggregate of 529 feet, is seen to be nearly half light-colored shale. The production of gas was so small as to be destitute of value. The best vein was struck at 136 feet, and salt-water came in at the same level, so that it was necessary to set the casing below this point. The well was counted a failure.

Numerous other wells have been drilled in Ashtabula county, no

records of which can be given here. Reference is made to some of these wells in Vol. I, Geology of Ohio, page 875. It has been made abundantly clear by the descriptions already given, that the uppermost 1,000 feet of the stratified rocks of Ashtabula county contain a vast supply of light and heat, and further, that this supply can be obtained at comparatively small expense. The accumulated power contained in the original forests of the country would make but an insignificant figure when compared with that to be derived from the gas which the underlying rocks contain. These great stocks of light and heat are sure to be more highly valued in the future, when other supplies become scarcer and more costly. There is no doubt that it will all be sought and used. As Newberry suggests, this great formation is also available for a supply of petroleum by distillation.

Lake County.

A few facts will be furnished in regard to the gas-wells that have been drilled in Lake county. Some of the earliest and best-known experience in the state in the utilization of natural gas is derived from this county. The facts are of the same character as those already given in the preceding section, all the geological conditions being essentially the same as in Ashtabula county. Wells have been drilled in Madison and other townships along the lake shore with fair success, but of which no records have been obtained.

Painesville.

Gen. J. S. Casement led the way in the utilization of gas in Painesville, and probably in northern Ohio. His first well was drilled in 1861, or thereabouts. Erie, Pennsylvania, had already drilled and turned to account a considerable number of wells, and the example was sure to be followed all along the lake shore, but the beginning of this utilization seems to have been made at Painesville. The first of the Casement wells was 700 feet deep, and yielded an excellent supply of gas for the residence and grounds of the proprietor. In fact, this well has proved a very satisfactory one. It has needed no care from the time of its drilling to the present, but year after year it has continued an uninterrupted, though not undiminished, flow. The volume has no doubt decreased considerably from its early days, and at the present time the well is probably producing less than 2,000 cubic feet per day. Such, at least, are the results derived from the somewhat unsatisfactory measurement by the anemometer that was made in 1885, the opportunity for which was kindly furnished by General Casement. The supply is at

present inadequate in the severest weather, the entire demands of the house, of course, being included, but for much of the year there is a considerable surplus unused, which shows itself in a back pressure of several pounds to the square inch. General Casement has drilled two other wells on his premises, but both are inferior to the first in value.

At least a score of similar wells have been drilled in Painesville and its immediate vicinity. The deepest of these was drilled by the late Hon. G. W. Steele for the supply of his residence. It was carried down to a depth of 1,390 feet. It ended, as it began, in the shale series. No advantage appears to have been gained by going deeper. The supply of gas obtained from it was not as vigorous as that derived from several other wells in the town. Mr. R. K. Paige secured an excellent and abundant household supply from a well drilled on his premises in 1885.

So far all the wells drilled in Painesville have produced gas, but in some of them the daily yield is very small. No opportunity for measurement could be obtained, except in the cases already acknowledged. Judging from accounts given, and the facts observed, the daily production of these wells will range from a very few hundred feet to a few thousand feet. The gas has not energy or volume enough for any general application or use.

Willoughby.

At Willoughby, several wells have been drilled and utilized within the last ten years. The flow has proved small in all cases, but enough has been found to be of economic value. A plan not found in operation at other points along the lake shore has been adopted here. The gas is introduced, as delivered from the well, into a small gasometer, the capacity of which is two or three thousand cubic feet. In this way there is always an available supply to be drawn upon, and the well that would be inadequate to meet the requirements of household use, if left to itself, becomes a reliable and sufficient supply for the dwelling, when prudently managed by means of this accumulation.

The remarks made under the preceding section as to the available supplies of fuel in the strata of Ashtabula county, can be applied with equal force to all the other counties in the lake shore tier in which the shale formation is found in full development.

Cuyahoga County.

Shale gas-wells can be counted by the score in Cuyahoga county. They have been drilled with success in every township on the lake shore, and notably in the city of Cleveland. At various points back from the

lake, wells have also been drilled, among which Berea and Independence may be especially named. In Berea, it is true, the famous sandstone that derives its name from the town is found in the geological section, but, as has been previously explained, the gas obtained from the wells is all shale gas.

Cleveland.

The experience of Cleveland, and its immediate vicinity, can be taken as fairly representative of the lake shore group. The general records and behaviour of twenty wells that have been drilled in this city were obtained in 1885. Since that time, a considerable addition has been made to the number. The wells on the west side of the river have, as a rule, proved much more serviceable than those on the east side, but no wells have, so far as known, proved entirely unproductive.

Numerous thorough tests have been made of the territory on the east side of the river by the drilling of deep wells, in addition to the remarkable well of the Cleveland Rolling-Mill Company at Newburg. Among these tests, the well of Mr. J. H. Wade, and one drilled by the Cleveland Gas Company, deserves special mentions. The exploration made by Mr. Wade were not only thorough, but so careful and accurate an account was kept of the work as it progressed in the deepest of the three wells drilled on the grounds, that it becomes altogether the most valuable of this field as far as it goes. The record, which is supported and confirmed by numerous samples of drillings from the entire section, was furnished to the Survey by Mr. Richard Roberts, under whose supervision the entire work was carried on. The well is located on the grounds of Mr. Wade, at the corner of Euclid and Case Avenues, and is about sixty feet above the surface of the lake. An unusually heavy deposit of drift is found at this point, as is seen below :

Drift beds	300 feet.
Blue shale	10 "
Black shale	40 "
Dark shale	25 "
Dark shale (somewhat lighter)	40 "
Gray shale	30 "
Black shale	10 "
Gray shale	185 "
Black shale (containing *Sporangites*)	15 "
Gray shale	60 "
Black shale (*Sporangites* abundant)	15 "
Gray shale	65 "
Black shale	55 "
Gray shale, calcareous	80 "
Limestone	60 "
Limestone, lighter in color	34 "
Dark limestone	23 "

The interval from the point where the limestones were first struck, to the bottom of the well, is about 600 feet.

The well was cased at 305 feet. Small gas veins were found, as usual, in the shale, the first of them, which was struck at 400 feet, being the best. At 1,120 feet, three feet of soft sand were found, and a fine sand occurred at 1,300 feet, and another bed at 1,370 feet. The first bed is near the place of the Orishany sandstone; the second is near the place of the Sylvania sandstone. Salt-water, strong and highly sulphuretted, rose to nearly the top of the well from these horizons. The well was plugged to shut out this unfortunate element. The Upper Helderberg limestone is seen to lie about 1,000 feet below the surface, or about 350 feet below tide. From Sandusky this stratum has descended nearly 900 feet. The well was not an entire failure. It yielded and continues to yield a small amount of gas, but the flow is very weak. A similar line of facts in all respects is found in the two remaining wells that were drilled upon the same ground. The production of all three is quite inadequate to the demands of the residence, but all there is of it is utilized. The second well was carried to a depth of 1,125 feet, and the third, to 1,739 feet.

The Cleveland Gas Company drilled a well in the central part of the city to a depth of 2,200 feet a few years since, but no valuable supply of gas was developed in it. The drill entered limestone at about 1,000 feet, and scarcely emerged from it in the further course of the work. A few sheets of sandstone were found interpolated in the great limestone series in the same order that has been previously described in the account of the deep Newburg well.

A well recently drilled on Euclid avenue furnishes a peculiar record. At 140 feet a bed of bowlders was struck, which was afterwards found to be fifteen feet thick and resting on the shale. This bowlder-deposit proved a reservoir of high-pressure gas. The force was great enough to throw stones as large as the pipe could carry out of the six-inch pipe. The storm abated in five days, so that drilling could be proceeded with. At 400 feet, a good vein of shale gas was struck. The well was located by Charles Latimer, Esq., with the divining rod.

Brooklyn Village.

As before stated, much better results are obtained on the west side of the city than on the east side, or in the central parts, already described. There are numerous wells in this district that are found entirely adequate to household supply. The best case for description is the well of Hon. J. M. Poe, near Brooklyn village, five miles from the public square. It is located in the valley of Big Run, from the shaly floor o

which gas has been escaping for an indefinite period. The well was drilled in 1885, and is 1,033 feet deep. In descending, more than a score of separate gas veins were struck. The gas was invariably found in light-colored and rather hard bands, under which darker layers of shale are found. The last 200 feet of the well were in light-gray shale, called white by the driller.

There were two "blowers" struck, one at 600 and a second at 750 feet. The latter had unusual vigor. It is said to have lifted the tools entirely out of the well, but like other accumulations of this sort, it proved short-lived, and two days made the limit of its active demonstrations. Salt-water was found at 125 feet, but the vein was weak and made but little trouble. Such occurrences are not at all unusual in the wells of this vicinity. The well was cased to 160 feet. When examined, a few weeks after its completion, the gas was still escaping uncontrolled. The volume of the flame was considerable, but an anemometer measure indicated less than 2,000 cubic feet per day. The well has since been connected with Mr. Poe's residence, and has proved ample for all demands.

The cases now given furnish a fair representation of the facts as they are found in and immediately about Cleveland.

Independence.

At Independence several wells have been drilled to considerable depths within the last few years. Some of them were sunk twenty years in the search for oil, and several within the last year or two. A company from Wellsville, New York, did the last drilling here in 1885. The well sunk by this company is said to be 1,800 feet deep, but the record was not made public. There is nothing to warrant the belief that there was anything of value to conceal. The drill is said to have reached the limestone at a depth of about 1,400 feet. The only result that was certain at this point in the scale followed in due time, namely, salt-water, which was said to have almost filled the well. When the drill was in the shale, small volumes of gas were set free, as usual. The well was undertaken in the search for oil, but apparently without due knowledge of the geological facts involved.

Rocky River

Several wells have been drilled within the last two years in the region of the Rocky River, or in the country immediately tributary to it. Mr. J. M. Gasser drilled two or more wells at Riverside Station for the supply of his green-houses, but the amount of gas obtained was entirely inadequate for the purpose named.

Other wells have been drilled in the same neighborhood, and the results are similar to those last recorded. No well misses gas altogether, and none obtain a really important amount.

Rockport Township.

Further up the valley, but in the same township, namely, Rockport, several very successful wells were drilled in 1885. Reference has already been made to one of them, namely, the well of H. A. Mastick, Esq., in section 9, near the Red Bridge. This well is located on a low uplift of the kind that so often traverses the shales in this vicinity. Along this break, gas has flowed from time immemorial. It rises through the water at some points, preventing freezing in winter, or escaping through the soil, it destroys vegetation for small areas around the vents. The direction of the arch is north 40° east, and the amount of the uplift in the portion of the shales that are exposed is about eight feet. Mr. Mastick drilled his well at the point where the gas was escaping most freely, and consequently found gas from the start. The amount was increased by small additions from many points as he descended. At 400 feet, however, he found a large vein, and another still larger at 500 feet. The last was particularly energetic when first struck. It threw the water and drillings from the well to a height of eighty feet. The section of the well is as follows:

Soil	5
Gray shale	200
Dark shale	200
Alternating bands of dark and light	122
Depth of the well	527

The last accession of gas came from the light-colored bands, which seemed to act as a sort of reservoir. This observation, indeed, applies to the entire district. A trifling amount of salt-water was found near the surface, and it is said that along the line of this uplift weak brine has always been escaping, forming one of the "deer-licks" of early days. The well was almost entirely free from water, and but forty-five feet of casing were used in it.

The flow of gas was measured a few weeks after the well was completed, and the daily volume escaping from the casing was found to be 21,643 cubic feet. Several other wells on adjacent farms have been nearly or quite as successful as the Mastic, well. They seem to have authenticated a generous supply of gaseous fuel for the neighborhood in which they are drilled. The facts as to the occurrence of the gas correspond in all respects with the records above given.

Several wells have recently been drilled at and near Berea, a brief account of which will here be given. All derive their gas supply from the Ohio shale, into which they descend, although the famous sandstone that takes its name from Berea makes the surface rock throughout the territory to which they belong. In some cases, however, the sandstone, though due, is wanting in the well sections, having been removed by pre-glacial erosion.

The first of these wells to be described is the one drilled by Mr. A. W. Bishop, at his residence in the village. The record of the well was carefully kept, and is attested by samples that were saved in the course of the work. It is as follows:

Drift beds	Soil and clay ..... 19 feet.		
	Gravel ..... 2 "	.....	21 feet.
Berea grit		.....	55 "
Light-colored soapstone, soft ...	15 feet.		
Hard sand-rock	8 "		
Light-colored soapstone, soft ...	4 "	(Bedford shale)	124 feet
Red shale	82 "		
White slate	15 "		
Brown soapstone	55 feet.		
Dark shale	20 "		
Light-colored slate	350 "		
Dark slate	155 "		
White slate	30 "		
Black shale	45 "		
White soapstone	45 "		
Black shale	45 "		
Light soapstone	30 "	(Ohio shale)	1,120 feet.
Black shale	50 "		
Light soapstone	15 "		
Black shale	30 "		
Light soapstone	215 "		
White shale, hard	15 "		
Black shale	15 "		
White shale, gas	20 "		
Black shale	35 "		

The Upper Hebberberg limestone was struck at 1,320 feet, and drilled into fifteen feet. Total thickness of the well, 1,355 feet. From the Berea grit to the Upper Hebberberg limestone the interval here is 1,241 feet. A question may be raised, however, as to the exact base of the Berea. The alternation of the shales above noted and the approximate thickness of the different elements can be learned from the section, but the exact thickness of each element was not an object of curiosity on the part of the driller, and the facts are given in round numbers, as is obvious from the record. The driller distinguished shale, slate and soapstone by the test of hardness. The plastic shales he called soapstone, and the hardest and firmest shales at the other extreme in this respect make the slates of this record. Gas was found in this well

at 600 and at 775 feet, and also, as noted in the record, near the bottom of the shale. But the supply is in fact quite small, all of it being used in a single residence without meeting even then the entire demands.

The well is now owned by the Berea Pipe Line Company, a corporation formed in 1886 to drill wells and supply gas to the town. This well is No. 1 of the new company. Eight wells have been drilled in all, or at least begun by the company. Numbers 2 and 3, which were drilled in the valley of the Rocky River to the depth of 980 and 735 feet, respectively, were failures. Nos. 4, 5, 6, 7 and 8 are located about two and a half miles northeast of the town, near a marsh called Lake Abram, where the surface indications of gas have always been conspicuous.

The pre-glacial valley of the Rocky River passes between the town and the most easterly of these wells. Well No. 7 was located in the old channel, and the drift has been penetrated 120 feet without reaching the bottom. Great difficulty has been experienced in driving the pipe thus far. The old channel has now been traced and mapped out from this point to Lake Erie, by Dr. D. T. Gould, of Berea. Its existence had already been recognized by Newberry, and a small portion of its course was pointed out by him. To the completion of this work, Dr. Gould has brought not only enthusiasm, but true geological sagacity as well. Of this eastern group of wells, Nos. 4, 5, 7 and 8 are productive, the last being more than equal to all the rest. Well No. 4 made a much greater display when first drilled than any of the rest, but after burning two or three weeks it was flooded during a heavy rain-storm, and the water lay upon the gas rock for two months. Under this invasion the gas was gradually suppressed, and when the water was finally removed, the gas was found to be quite feeble. The record of this well is as follows:

Drift, clay and sand	50	feet.
Bedford shale, red	.....	"
Small gas veins at 63, 100, and	150	"
Strong gas vein at	230	"
Small gas vein at	300	"
Small gas vein at	340	"
Light-brown shale	500	"
Strong gas at	573	"
Light-blue shale	845	"
Strong gas in black shale	850	"
Gray shale beginning at	850	"
Black shale		
Upper Helderberg limestone	1,206	"
Well finished at	1,240	"

The record of No. 8 is as follows:

Drift	21 feet.
Small gas veins at	100, 160, 240, and 310 "
Stronger vein at	350 "
Small gas vein at	510 "
Shale changed to dark-brown at	510 "
Light-blue shale at	875 "
Light-blue shale	900 "
Well finished in dark shale	960 "

No. 7 was drilled 300 feet into the limestone, but no advantage was derived from going below the shale. The strongest supply of gas seems to come from the points where changes occur in the shales and between 800 and 900 feet. The darker beds seem most productive of gas.

The production of four of these wells was measured on October 16, 1886, with the anemometer. Well No. 4 was found to be producing from a $2\frac{3}{8}$ inch pipe, inside measure, 52,000 cubic feet per day. No. 5 was found to be producing 8,000 cubic feet per day, and No. 7, 11,000. The flow from No. 8, through the same sized pipe used in the other wells, was 99,475 feet, but from the casing of the well the flow was at the rate of 127,000 cubic feet per day. The aggregate production from the $2\frac{3}{8}$-inch pipes is 170,000. The company has proceeded to pipe the gas from these wells to the village, using four-inch pipe in the mains. The results were counted satisfactory at the date of the last report.

The pressure of the wells has been found to be different on different days. Observations were made by the officers of the company on October 8th, and again on October 13th, and the records are as follows:

Well No. 4.

October 8th.	October 13th.
$\frac{1}{2}$ lb. in 1 minute.	$\frac{1}{2}$ lb. in $\frac{1}{2}$ minute.
$1\frac{1}{2}$ lbs. in 3 minutes.	1 lb. in $\frac{3}{4}$ minute.
2 lbs. in 7 minutes.	$1\frac{1}{2}$ lbs. in 1 minute.
3 lbs. in 10 minutes.	3 lbs. in $1\frac{1}{2}$ minutes.
	4 lbs. in 2 minutes.
	5 lbs. in $2\frac{1}{2}$ minutes.

Well No. 5.

October 8th.	October 13th.
$\frac{1}{2}$ lb. in $2\frac{1}{2}$ minutes.	$\frac{1}{2}$ lb. in 2 minutes.
1 lb. in 7 minutes.	1 lb. in 5 minutes.
	5 lbs. in 24 minutes.

Well No. 7.

October 8th.	October 13th.
1 lb. in 3 minutes.	1 lb. in 3 minutes.
2 lbs. in 5 minutes.	2 lbs. in 5 minutes.
3 lbs. in 7 minutes.	3 lbs. in 7 minutes.
5 lbs. in 10 minutes.	5 lbs. in 10 minutes.

Well No. 8.

October 8th.	October 13th.
3 lbs. in 1 minute.	3 lbs. in 1 minute.
20 lbs. in 4 minutes.	20 lbs. in 3½ minutes.
25 lbs. in 6 minutes.	25 lbs. in 5 minutes.
35 lbs. in 10 minutes.	35 lbs. in 9 minutes.

By reference to the weather records for these days it was found that the barometer was 30.25 in. on the 8th, and on the 13th, 30 06 inches. A connection between barometric changes and the flow of gas wells is very often asserted and insisted upon by practical men in charge of the wells, but the figures above given are the first that it has been possible to obtain that show any relation between the two lines of facts. The connection in this instance may be purely accidental, but the subject is of interest enough to justify publication of these observations. The desirability of more facts of this character is obvious.

Lorain County.

All the wells that have been drilled for gas or oil in Lorain county belong to the division which is under consideration. The only gas found here comes from the great shale formation, although there is a large district in which the Berea grit either makes the surface-rock, or else is found under shallow cover. Lorain county, in fact, holds the most valuable deposit of this formation of any county in the state. At Belden, as already shown, this stratum, a few years since, proved to be an oil-rock of small capacity and value, but its production is now entirely suspended.

The number of wells that has been drilled in this county is large. More or less exploration has been going forward since 1865. The surface indications of oil and gas that belong to the shales generally, are responsible for the earliest work that was done in this field; but these indications were misleading in every case, so far as oil is concerned, for reasons that we can now very well understand. At the present time, these same indications are again made to serve as the basis of extravagant expectations of high-pressure gas at many points in the country. It is needless to say that such expectations are doomed to disappointment. We are warranted in declaring, after all the work that has been done in this formation, that it nowhere contains in Ohio stocks of high-pressure gas, aside from the short-lived "blowers," the occurrence of so many of which has already been chronicled. These, it is to be understood, are likely to be found at any point in the series, but they are of no value, either in themselves, or as indications of large and permanent supplies. Demands that are made upon the shales for what they have

to give, are fairly honored; but, too often, the formation is expected to give what it never had, namely, accumulations of gas on the large scale that are durable enough to repay utilization.

Sheffield.

The record of the well drilled at Sheffield, on the lake shore, a number of years since, by Jay Terrell, Esq., is given herewith. The well was begun in black shale:

Black shale	280 feet.
Light-blue and gray shales	110 "
Light-gray shale, soft	15 "
Black shale, very hard	10 "
Reddish-brown shale	84 "
Black shale, hard	10 "
Light-gray shale, soft	40 "
Dark-gray shale	25 "
Darker shale	23 "
Dark impure limestone, filled with minute shells of pyrite	17 "
Soft, light-gray shale	18 "
Dark-gray shale	41 "
Total	674 "

Gas was found all the way down in the shale series. Following the record above given, 182 feet of limestone were next penetrated. The limestone was in various shades of color and hardness. Salt-water was struck at 689 feet in its upper beds, and continued from this point down as far as 720 feet. The well was drilled for oil, and was a failure in that respect. A trace of oil was found, such as very often occurs in the shales. The limestone was full of salt-water, and that only.

Brownhelm.

A well was recently drilled for gas in Brownhelm Hollow, in the valley of the Vermillion River, by S. H. Bacon, Esq. The special object of drilling the well was to obtain a supply of gas for steam-power, to be used in the flouring-mill that is located here. The record, as kept by the driller, Mr. Charles Keith, is as follows:

Shales, mixed black and blue	60 feet.
Shales, black or brown	90 "
(Gas and brine at 150 ft.)	
Black shale	60 "
Blue and soft shale	30 "
Brown shale	6 "
Blue and brown shale, mixed	27 "
Blue shale	8 "

Very dark shale	40 feet.
Reddish-brown shale	30 "
Blue shale	6 "
Slate mixed, blue and brown	53 "
"Soapstone"	100 "

At 520 feet the Upper Helderberg limestone was reached, and drilling was continued in it for 220 feet. The uppermost 50 feet proved very hard. The shales yielded a little gas. When the well is locked in, the pressure rises to a maximum of 15 pounds to the square inch, but the gas does not escape in large enough volume to move the anemometer, either from the casing or from the pipe. This fact is significant in connection with the mode of estimating the production of wells by their pressure. If the yield were even 1,000 cubic feet per day, it is probable that the anemometer would register it, especially from a two-inch pipe. According to the empirical rule that was stated on a preceding page, but which was promptly rejected, the yield of the well ought to be 22,500 cubic feet per day. The largest volume of gas found in the well came in at 152 feet, but as it was accompanied by oil and salt-water, it was necessarily excluded by the casing, which extends to 190 feet. A little salt-water was also found lower in the well and presumably in the limestone series.

In the valley near by, gas is continually issuing through the water from the joints and fissures of the shale, which makes the bed of the river at this point. There is nothing obvious at these points in the way of arches of the strata of any persistency or of notable proportions, but the same uneasy disposition of the strata that has been described in connection with so many exposures in northern Ohio, is also found here.

Lorain.

Several deep wells have recently been drilled at Lorain, and all have been successful in their search to the extent of finding gas, at least in small quantity. The last well, drilled on the grounds of the brass works, is said to be the largest producer. The shales come to the surface here, being covered with a very thin layer of soil, or drift deposits, at most. The series is about 900 feet thick, as is proved by the drilling of the second well, sunk by Gilbert Hogan, Esq. The first is between 900 and 1,000 feet deep. It descends far enough into the Devonian or Upper Helderberg limestone to reach the peculiar mineral-water that characterizes these deep horizons. The composition of the water is seen in the accompanying analysis made for the Survey: (*Lord.*)

	Parts in one thousand.
Chloride of calcium	37.370
Chloride of magnesium	22.430
Chloride of sodium	48.599
Chloride of potassium	1.460
Bromide of sodium	0.601
Sulphate of lime	0.712
Carbonate of lime	1.210
Iron, alumina and silica	0.064

Specific gravity of the water at 60 F., 1.0837.

The water rises to within fifty feet of the surface, and the well, also' yields a small flow of gas derived from the shales. Mr. Hogan has already made provision to utilize the water for medicinal purposes on the large scale. He has built thoroughly equipped bathing-rooms, and a hotel is in process of construction. The heat for the bathing-rooms is supplied by the gas of the well. The Devonian Spring, as the establishment is appropriately named, is already acquiring a reputation for the cures that are worked by it. It is not to be doubted that water of the character named above can be made to relieve, under proper medical direction and control, many human infirmities and ailments.

Erie and Huron Counties.

Considerable drilling has been done in the shale formation of Erie county, especially in the valley of the Vermillion River, within the last twenty years, and the facts in this region are well shown in the drilling that has recently been done in Brownhelm Hollow, which is described on the preceding page. The shales are rapidly reduced in thickness, as they are followed westward to their final outcrop near Sandusky, and the chances for the low-pressure gas, that belongs in this series, are correspondingly decreased. An account has already been given in another chapter of the deep wells drilled at Milan, in 1885, and at Sandusky, in 1886. Another well of the same character is now being sunk at Birmingham. The shale gas-wells appear to be mostly found in the eastern half of the county. No detailed statements are needed in regard to them. The facts are altogether similar to those already given from adjoining counties.

Monroeville.

A well drilled at Monroeville, in June, 1887, found a vein of gas in the lower part of the great shale series, of which the promise was brilliant, but the performance disappointing. It yielded a considerable volume of gas at good pressure for a few days and then died down to small proportions.

The record of the well, as furnished by Mr. G. W. Drake, is as follows, viz.:

Blue shale, dark	20 feet.
Black shale, yielding gas	84 "
Hard limestone (pepper and salt rock)	8 "
White, soft shale, with gas	50 "
Hard-shale, light-colored	15 "
Light-colored limestone, very hard	200 "

The well was carried deeper, but the subsequent records have not come to hand. Nothing of value has been reported since the shales were passed.

New London.

At New London, Huron county, a well has recently been sunk to the limestone, which was reached at 998 feet, or 18 feet below tide-level. The record of the drilling is as follows: Drift, 90 feet, comprising blue clay, 40 feet; sand and gravel, 50 feet; Cuyahoga and Berea shale, 75 feet; Berea grit struck at 165 feet, or 815 feet above tide, 83 feet thick, in two divisions, 52 feet of fine-grained sandstone, and 31 feet of so-called water-sand. At two feet in the stratum a large amount of fresh-water was found. Salt-water was struck lower in the rock. The well was cased at 260 feet. The Bedford shale was 95 feet thick, and red throughout. The Ohio shale was struck at 355 feet. The upper beds were blue. To 451 feet, the color grew constantly darker, but it turned light at this point, and thenceforth alternated between blue and black beds to the depth of 900 feet, where the shale became quite light, being reported white shale by the driller. The limestone series was reached, as above stated, at 998 feet. The interval from the Berea grit to the limestone is here 833 feet. The well is exceptional in this respect, that it produced neither gas nor oil in appreciable quantity. There is not often a complete failure within the geological limits here traversed. A bed of sharp and clean sand was found in the drift directly under forty feet of boulder clay. This sand contained a small quantity of oil, which must have ascended to it from the underlying Berea shale. The currents of high-pressure gas at Wellington in the bed of the same creek, and in like situation, will be remembered. It thus appears that in this region there is an oil and gas-sand in the drift deposits under only 40 feet of cover.

Norwalk.

A citizens' well is now being drilled at Norwalk, the record of which to September, 1887, has been kindly furnished by Mr. C. H.

Gallup. The record consists in drillings saved with intelligent care and duly authenticated. From it the following order of formations is deduced:

Drift		85 feet.
Ohio shale	Shale, mainly black... 203 feet. Dark limestone..... 10 " Shale, light-colored... 142 "	355 "
Devonian limestone		110 "
Lower Helderberg limestone. (Gypsum at 600, 800, 1,153 feet, etc.)		615 "
Niagara limestone		215 "
Niagara shale		25 "
Clinton series		123 "
Medina shale		242 "
Hudson River shale (to date)		534 "

The well is directed to the Trenton limestone, which should be reached between 2,650 and 2,750 feet.

The record above given is the most satisfactory that has yet been obtained of this part of our scale in northern Ohio. No important flow of gas has been reported from the well thus far.

Central and Southern Counties.

From the above-named counties southward, no use has been made of the shale-gas, so far as is known, except at the points already named in a previous chapter, namely, Shelby and Crestline. The use at these points has been small, at best, and but for short periods; but the fact of the presence of an available supply in these localities is established by this experience. It is doubtful whether the structure of the shales is as much broken or disturbed in central and southern Ohio as in the northern part of the state. Certainly the indications of gas are less frequent and less promising than in the former district. They are, however, common enough even here to have led to many attempts to find supplies of gas or oil in this horizon, especially during the last two or three years. Gas has been found in small volume at very many localities within the district now under consideration. Wells drilled at Sunbury, Westerville, Canal Winchester and other towns, owe what gas they found to the shales. Monotonous and uninterrupted dip is unfavorable to accumulation, as has often been pointed out in the preceding pages of this report; and it is to these conditions, perhaps, that most of these failures are due. In the southern counties, the shales were tested at many points in the petroleum excitement of twenty years ago; and the discovery of veins and "blowers" of gas was made in many of these fields,

but as oil was the object of search at that time, no especial interest was attached to the gas production. It is not to be doubted that Ross, Pike and Scioto counties will supply from this source a large amount of light and fuel, in time to come, if proper conditions for the search are found and observed. The entire shale formation is, however, reduced in these same counties to its lowest terms for the state of Ohio, and less is to be expected of it here on this account. The great service of the shales in the way of petroliferous production, whether of oil or gas, is, after all, not in outcrop, but under cover, and where the appropriate reservoirs are present to do the all-important work of storage and accumulation.

CHAPTER VI.

THE HISTORY AND DEVELOPMENT OF THE MACKSBURG OIL-FIELD.

By F. W. Minshall.

DISCOVERY OF PETROLEUM IN OHIO, 1860 TO 1864.

Although the quantity of petroleum thus far obtained from the sandstones of Carboniferous and Subcarboniferous age in southeastern Ohio is insignificant when compared with the yield from the deeper sandstones of Pennsylvania, a history of this branch of mining industry, it is hoped, may be interesting to the general reader, and may, also, reveal some points that will be valuable in the future development of the resources of the state. Over forty years ago, long before the idea of drilling for petroleum had occurred to Col. Drake, or to any one else, the oil was collected from the sand-pits of Hughes River, in West Virginia, and sold as "Seneca Oil" to Messrs. Bosworth & Wells, in Marietta, Ohio. It was purchased for 25 cents per gallon, and the first shipment of five barrels was made by them in 1843, from Marietta to New York, by way of New Orleans. The oil was sold on arrival in New York to a drug house, at 90 cents per gallon. Messrs. B. & W. continued dealing in the oil for about ten years, purchasing from one to two hundred barrels per year, from the Hughes River producers, and selling it to dealers all over the country. Large quantities of it were purchased by the makers of the once-celebrated "Mexican Mustang," and "Nerve and Bone" liniments. The oil was obtained from the lands of Mr. Bushrod Washington Creel, and was a source of considerable revenue to that gentleman, as well as to those who gathered it. Messrs. Bosworth & Wells may, therefore, justly claim to be the pioneer oil-dealers of Ohio. Considerable quantities of the "Seneca" oil were also collected from wells drilled at an early day for brine at different points in West Virginia and Ohio. The first petroleum obtained from the Duck Creek Valley, in Noble county, Ohio, came from wells of this kind.

The process of drilling wells for the express purpose of obtaining petroleum in Ohio, followed closely after the first successful experiment made in the valley of Oil Creek, Pennsylvania. After it had been demonstrated that large accumulations of this valuable liquid could be found in the underlying rocks, by drilling into them at points where the gas was seen bubbling through the water or the greenish fluid was seen floating upon its surface, wells were started where such surface indications could be found.

The Cow Run Oil Field.

In the winter of 1860, Mr. John Newton, of Marietta, Ohio, was one day sitting in his office at the "Harmar Bucket Factory," when his attention was called to a newspaper article on the subject of drilling wells for petroleum in Canada. In the article, natural gas-springs were mentioned as an indication of underlying deposits of oil. Mr. Newton read the article aloud. Among the listeners was Mr. Uriah S. Dye, one of the workmen at the factory. After the reading was finished, Mr. Dye informed Mr. Newton that he had one of those gas-springs on his farm, at Cow Run, in Lawrence township—that the spring had been a subject of curiosity for many years to the owners of the land, and that a crude attempt had been made to use the gas as fuel by a Mr. Guyton, who had a cooper shop near the spring. Mr. Newton was finally persuaded to go out with Mr. Dye and look at the spring. As a result of the investigation, a company was formed, composed of Jno. Newton, Douglass E. Newton, William Naylor, Moffatt Dye and George S. Bosworth. On the 2d of February, 1861, leases were taken by the company from Uriah S. Dye, covering the W. $\frac{1}{2}$ of N. W. qr. of section 19, and W. $\frac{1}{2}$ of S. E. qr. of N. W. qr. of same section, in all 100 acres; also, from Samuel Dye, the N. E. qr. of N. W. qr. of section 19, 40 acres. Drilling was commenced at once, the first well being located close to the gas-spring. The machinery then in vogue for drilling was the "spring-pole" and "treadle;" the motive power, human muscle. In that day it was essential that the driller be sound in both wind and limb. The first Newton well was, however, soon "kicked" down to what was then supposed to be a sufficient depth, and "came in dry," barely showing enough oil to grease the tools. Instead of being discouraged, Mr. Newton seized a shovel and said, "Come, boys, I'll show you where to get an oil-well." He went over to the Samuel Dye 40 acres, chose a spot on the main run where the gas could be seen bubbling up through a pool, and by night had a pit dug down to the gravel. In the morning the water in this pit was covered with oil. The "kicking process" was speedily resumed, and at

a depth of 137 feet their labors were rewarded by striking a "gusher." The well did not flow; it was pumped with the spring pole, and each day's product put into barrels—the pumping and filling of fifty barrels was about an average day's work for two men. The oil was taken by wagon nine miles to Marietta, and sold chiefly to Mr. William Finlay, buyer for a refinery located at St. Louis, Mo.

The Newton Company drilled seven shallow wells upon the Dye farms, all of which, except the first one, produced more or less oil.

Discovery of Petroleum at Macksburg.

Previous to the drilling of the last-named wells, however, in the fall of the same year, 1860, Mr. James Dutton, in company with Alden T. Warren and John Smithson, decided to drill a well on the bank of Duck Creek, near the northwest corner of Mr. Dutton's farm, in Aurelius township, about one-half mile below the town of Macksburg. They had often noted the oil spreading over the surface of the creek at that point, and, as Mr. Dutton says, the boys used to get the oil on their backs when they went in swimming. The location selected was on the adjoining farm of Mr. William Rayley. On the 18th of August, 1860, a lease was given to James Dutton for a strip of land two rods wide, fronting on Duck Creek. The term was for 99 years, the consideration one hundred dollars, to be paid at the expiration of ten years; search was to be made for rock oil, and if no oil should be found, land was to revert to the owner, and no money to be paid. Mr. Dutton made arrangements at once to have the drilling-tools made, and as soon as they were ready work was commenced. The method of drilling adopted was even more laborious than the "spring-pole," the tools being raised by a hand-lever. At a depth of about 59 feet a valuable vein of oil was struck. The gravity was 28° B., and Mr. D. found difficulty at first in disposing of it, on account of its heavy gravity. Its value as a lubricating oil was, however, soon discovered, and the oil eventually brought as much as $28.00 per barrel. This well was also pumped by hand; the oil filled into barrels and taken by wagon ten miles to Lowell, on the Muskingum River, from which point it was shipped by boat to Pittsburgh.

The successful issue of the Dutton well at Macksburg, and of the Newton well, at Cow Run, soon caused derricks to spring up rapidly in their immediate vicinities. The most important of these at Cow Run, was one known as the "Elm Tree" well, which was drilled on a farm which adjoined the S. Dye tract, by Lemuel Wheeler and others. It followed closely after the first Newton well, and produced at the rate of 100 barrels per day. Among those who were drawn to Cow Run by the fame of the "Newton" and "Elm Tree" wells, was Col. John H. Weare,

a pioneer operator in the Burning Springs district of West Virginia. In the year 1860, he had drilled a shallow well in that field, which, at the beginning of the war, was producing handsomely, when a raid was made upon the field by the rebel General Jones, and the property burned. Colonel Weare then went to Cow Run, where he was known for several years as one of the most active and enterprising operators in the field. Messrs. McFarland Brothers, of Pennsylvania, were also among the earliest operators in both the Cow Run and Macksburg fields.

Extensions of the Oil Fields.

The search for petroleum was not confined to the waters of Duck Creek and Cow Run, but was prosecuted along the beds of other streams. The manner in which this search was carried on affords a curious example of the tendency to act upon simple inferences drawn from imperfect premises. It was first inferred that the productive oil territory would be confined to the bottom lands along the water-courses, because the surface indications were found upon the surface of the streams. Hence, many of the leases taken for oil purposes only covered such parts of the farms as lay along the streams. This was designated as "the boring territory," and all other parts of the farm were considered valueless for oil purposes. Again, because the oil in the Dutton well was 59 feet below the bed of Duck Creek, and in the Newton well 137 feet below the bed of Cow Run, it was supposed the oil would be found at like distances below the beds of all other streams in the surrounding country. Two hundred feet was, therefore, usually adopted as the regular depth for a test well, and as this distance could be drilled by human muscle, with the aid of the spring-pole and treadle, nearly all of the drilling that was done prior to 1864 was done in that way.

Geological Horizons of the Oil Production.

The oil in the Newton wells came from a sand-rock which belongs in the Lower Barren Coal Measures, between the Ames and Cambridge limestones. At Cow Run, on the Dye farm, the top of it lies 137 feet below the bed of the run, and at Macksburg, on the Dutton farm, about 125 feet below the bed of Duck Creek. The heavy oil in the Dutton well at 59 feet was probably a surface accumulation that had escaped from this sand-rock and gained specific gravity from contact with surface-water. The rock is a white quartz sand from 25 to 50 feet thick, some layers of which are filled with large quartz pebbles. Its nearness to the surface enabled the gas and oil to escape through small fissures, and these "shows" caught the attention of the oil-seeker, not only upon

the Dye and Dutton farms in Washington county, but also upon the Joy farm on Sharp's Fork of Federal Creek, and the Williams farm on Buck Run, in Morgan county. At all of these points shallow wells were drilled as early as 1861, and comparatively large quantities of oil obtained during the periods now under review. The Joy and Bishop farms on Federal Creek, and the Williams, Stanton and Scott farms on Buck Run, were the productive farms from this sand-rock in Mo gan county, and on these farms the rock was nearer to the surface than in Washington county, being from 80 to 100 feet below the beds of the streams named.

About 400 feet above the sand rock just described, is another of similar character and texture; this is the sand which lies immediately over the Macksburg (No. 10) coal. In the Macksburg and Cow Run oil fields it lies from 325 to 350 feet above low water at Marietta. In other parts of Washington county, however, it lies below drainage, and at such points often causes a well-marked surface-show of oil. Among other places, the following may be named where there was sufficient "show" to induce parties to drill prior to 1864: 1st. Bed of Duck Creek, near north line of Marietta township, well drilled by Perkins & Nugent; tools lost and abandoned. Well on Thomas Chambers', southeast section 18, Marietta township; small production of oil from sand last described, at 150 feet below bed of run, erroneously supposed to be equivalent of first Cow Run sand. 2d. Bed of Long Run, southeast quarter of section 34, Newport township; small production from same sand at 100 feet below bed of run. 3d. Bed of Newell's Run, northeast quarter section 12, Newport township; same sand exposed in the bed of the run, from which several barrels of oil were taken with a hand-pump.

Thus, it will be seen that prior to the summer of 1864, the only points in Washington county which could be called productive territory, were Macksburg and Cow Run, and these were producing from the sand (Buffalo?) which lies between the Ames and Cambridge limestones. When a superfluity of currency led to the speculative mania of 1864, the Ohio oil-field became one of the objective points; the small production above described was considered an indication of larger deposits, and many stock-companies were organized for the purpose of bringing forth the enormous treasures supposed to be hidden beneath the hills of Washington and Noble counties. Some idea of the scale of operations may be formed from the following imperfect list of companies organized for work in this field:

	Capital.
Bergen Oil and Coal Co., of New York	$2,000,000
Marietta Mining Co., of New York	2,000,000
New Jersey Oil Co., New Jersey	1,500,000
Eagle Oil Association, New York	.....
Equitable Petroleum Co., New York	.....
Willow Glen Petroleum Co., Philadelphia	300,000
Crescent Petroleum Co., Boston	250,000
Williamsport and Ohio Petroleum Co., Williamsport, Pa	220,000
Marietta Oil Co., Boston	250,000
Cincinnati Petroleum Co, Cincinnati	250,000
Boston Petroleum and Mining Co., Boston	600,000
Duck Creek Petroleum and Mining Co, Cincinnati	200,000
Putnam Petroleum Co., Dayton, O	200,000
Union Coal Co., Marietta	100,000
Archer's Fork Oil Co., Marietta	100,000
Ohio Oil and Mining Co., Marietta	100,000

The Speculative Era, 1864 to 1877.

Nearly all of the lands in Washington and Noble counties, and in neighboring counties of West Virginia, were leased for oil purpo es for from ten to twenty years. The competition between companies caused lessees to agree to commence "operations" for mining purposes within from thirty to ninety days from the execution of the lease, under penalty of forfeiture. In many cases the papers were so loosely drawn that the putting in of a conductor was considered a sufficient "commencement of operations" to prevent forfeiture. In the majority of cases this was as far as operations ever advanced. A few of the stock companies, however, made preparations for active operations in the field; conspicuous among them was the Bergen Oil and Coal Co., of New York. This company, under the management of Mr. William Frazier, purchased in May, 1864, from the Newton Company, the unexpired term of lease on the two Dye farms, for a cash consideration of $25,000; the total production of the two farms was, at the time, only ten barrels per day. For an additional sum of $38,000 the company purchased the fee of the farms, thus gaining control of the 180 acres. In the winter of 1864–5, the company bought ten boilers and engines, ten sets of James Bown's drilling tools, ten 250-barrel tanks, and a large stock of assorted hardware for drillers' and rig-builders' use.

Early Drilling Tools.

The drilling tools used in the Bown wells were composed of a twenty-foot drill-bar, two inches in diameter, an eight foot sinker-bar, and jars in proportion; the complete string of tools was about forty feet long, and was worked in a derrick forty five feet high, and fourteen feet

square at the base. The temper-screw was about three feet long, and instead of working between open reins, as at present, was enclosed in a close round sheath; when the screw was run out, the driller, instead of opening the reins and sliding the screw back to place, had to grasp the sheath and start the clamps at the end of the screw, whirling backward in a circle until the screw worked its full length back into the sheath. A Brooklyn dentist who came out to Cow Run to act as superintendent of an oil company, took hold of the tools one day to turn them while the driller was temporarily absent; he kept turning out the screw until he was suddenly startled by the clamps striking the floor with tremendous force. Looking curiously at the screw the doctor exclaimed, "'Psha! I thought there was a *nub* on the end of it." The cutting was done with a chisel-shaped center-bit, followed by a reamer. The Cow Run drillers are entitled to the credit of having first discovered that the reamer was a superfluous tool, and that the center bit could be so modified that it would drill a true round hole, and thus save time and greatly diminish the risk of fastening tools in the well. Instead of the long chisel-shaped taper, the bit was made thick for its entire length and brought to a cutting edge with a short bevel; the thickness of the bit at the top of the bevel, when dressed as the arc of a circle, gave a reaming face which answered every purpose.

The driller sat upon a high stool and turned the tools; convenient to his hand was a wooden maul, with which he knocked the "follower" loose on his temper-screw when he wished to let out a little jar. Compared with the driller of to-day he was rather a drowsy-looking fellow, and he drilled about one foot to the modern driller's ten.

The kind of machinery used, although an improvement upon the "spring-pole and treadle," was inferior to that in present use. In many cases a direct connection was made by the pitman between the walking-beam and the crank-pin of the engine, without the intervention of counter-wheel and belt. The link for reversing was not in use, and it was necessary to go to the engine and shift the cam-rod if any reverse motion was needed. This direct attachment was used by the old salt-well drillers, who used poles instead of a cable.

Testing the Territory.

The Berger Company's engines were distributed as follows: Two on Archer's Fork of Little Muskingum River; one on Little Muskingum, near the mouth of Bear Ran; one near the mouth of Newell's Run; one on Duck Creek, below Salem; two on Pawpaw Creek; one on

Long Run, and two on Cow Run. Unfortunately the company became financially embarrassed early in the summer of 1865, and suspended active operations before any of its test-wells had been brought to a successful issue.

The New Jersey Oil Company purchased the James Dutton farm for $100,000, and also the Jacob Dearth farm. Seventeen new engines were purchased in Cincinnati, and twelve sets of drilling tools. Seven engines were placed on the Dearth farm, one on the Dilley farm, one on the Riley farm, one on the Fowler, one on the Corp, and two on the Middle Fork of Duck Creek, near Middleburg.

One well was drilled on the Dearth farm to a depth of 1,200 feet. This well passed through what is now known as the salt-water sand, and having considerable gas, flowed at intervals with great force for several years, throwing out a large quantity of brine but no oil except a little from the upper sand-rocks. No oil was obtained by the New Jersey Company except what was pumped from a few shallow wells; it, therefore, soon ceased active operations and re-sold the Dutton farm to its former owner at a heavy discount. The Jacob Dearth farm is the one now owned and operated by Messrs. Borkman and Laney.

The Eagle Oil Association, of New York, was organized in 1864, for the purpose of developing the Dearth farm, which lies at the mouth of Indian Run, a small stream putting into Duck Creek opposite Macksburg. A consideration of $300,000 was paid for the 200 acres on the strength of a small well which had been drilled on the farm at the mouth of the Run. This well, then known as the Gilchrist well, was pumping about ten barrels of heavy lubricating oil per day, and the oil was selling for about $20 per barrel. The Eagle Company placed machinery on the farm in 1865 and did some little drilling, but never obtained any oil except that which was pumped from the "Gilchrist" well.

In the same year the "Madison Oil Company" obtained one acre for a consideration of $500, on the Atkinson bottom just below Macksburg. Machinery was put on the ground and a well drilled through the 500-foot sand. It is reported to have started at about fifty barrels per day, and continued to pump ten barrels for several months. This was the first paying well from the 500 foot sand.

The Equitable Petroleum Company placed machinery, in the same year, on the Dutton farm, about one mile below Macksburg. The well was drilled to 800 feet and found considerable gas and some oil in what is now known as the 700 foot sand.

A well was also drilled on the Rayley farm, which found a good

showing of oil in the 700-foot sand, but its owners, a Pittsburgh company, failed to make it productive and abandoned it.

Some two or three wells were drilled by the "Acme Oil Company," on the John Smithson farm, below Macksburg. The wells pumped considerable oil from the 300-foot sand, but were soon exhausted.

Mr. Jefferson Delong also drilled a well on his lot in the town of Macksburg, with unfavorable results. This is the lot on which the Bailey gas-well now stands, which supplies the National Transit pumping-station with fuel.

The Bergen Company, which held a lease of the Markey farm, in the village of Macksburg, sub-let a part of it in the spring of 1865 to parties who drilled a well to 600 feet, striking a small showing of oil in the 500-foot sand.

The Lowell Oil Company, in the same year, drilled a well on the tract near Macksburg, now owned by George Rice, Esq., striking a fair well in the 500-foot sand.

Mining for Oil.

Among the novel features of the work at Macksburg in 1865, was the sinking of a shaft by the Moorehead Oil Company, on the Rayley farm, for the purpose of obtaining the Dutton vein of lubricating oil. A well was first drilled down to the vein which yielded a little oil with a large quantity of water. The owners then conceived the idea of putting down a shaft into which it was supposed the oil would flow in great quantity. The work was finally completed at great cost, but no more oil was obtained from the shaft than the well had yielded. Another company, which held a lease on the adjoining land, contemplated digging a trench to the depth of the Dutton vein across his leasehold, but abandoned the project after the completion of the shaft.

A large sum of money was also expended by the Boston Petroleum Company in sinking a shaft for shallow oil on Eight-Mile Run in Newport township. A well known as the "Eastwood" was drilled, about the same time, on the bank of Duck Creek, just below South Olive in Noble county, and found a good well in the Macksburg 300-foot sand. This well continued to yield oil in paying quantity for a number of years.

Mr. Harvey Kilmer located and drilled a well on the East Fork of Duck Creek, at the mouth of Gould's Run, striking a large flow of gas and a little oil in the 500-foot sand.

Further Development of the Field.

The Germania Oil Company drilled to the depth of 800 feet at the mouth of Pawpaw Creek, near Salem, with some showing of oil in the 500-foot sand.

The Willow Glen Petroleum Company placed machinery and drilled on Burns' Run, in Newport township, with unfavorable results.

The Marietta Mining Company drilled on Kilwell Run, in Fearing township; tools lost and well abandoned.

John M. Rounds, of Summerfield, Ohio, and Thomas Conley, of Parkersburg, W. Va., drilled on Newell's Run, with fair shows of oil in the shallow rocks.

Although the wells above enumerated as having been drilled in the years 1864 and 1865, when taken collectively, discovered oil in paying quantity in the 140-foot sand, the 300-foot sand, the 500-foot sand, and the 700-foot sand, the result of each company's operations was so unsatisfactory that the Bergen, the New Jersey, the Eagle and the Equitable companies all withdrew from the Macksburg field.

While the above work was in progress matters were almost at a stand-still on Cow Run. The Bergen Co. having suspended drilling, was pumping its ten barrels per day from the two Newton wells. The oil was bringing a good price, selling in the summer of 1865 for $14 per barrel at the wells. The company finally decided to divide its Cow Run territory into two-acre lots and sub-let them at one-third royalty. The first lease was taken by Isaac Perkins in March, 1886; three lots of two acres each were let with the understanding that he was to drill to a depth of 600 feet unless a paying well should be sooner obtained. The first well was begun soon after the lease was taken, but was not completed till the following winter. The well-head is forty-eight feet below the Pomeroy coal, and 666 feet above sea-level. In the Cow Run field the shales of the Lower Barren Coal Measures gave the driller a great deal of trouble by caving in and filling up the drill-hole. It was found necessary to case from one to three times with sheet-iron casing to shut out these caves. The tools were lost several times in the Perkins well, but were fished out again, and in November, 1866, the top of the second Cow Run sand was struck at 595 feet. When the bit had penetrated the sand about five feet the well began to flow. It was tubed with two-inch pipe and a seed-bag, and turned into a 250 barrel tank, which it filled in two days. The well continued to flow 100 barrels per day for several months, and kept its owners busy building tanks to hold the product, the only means of transporting the oil to market being by wagon nine miles to Marietta over roads which were at that time of year almost impassable.

The sand-rock from which this oil was obtained is supposed to be the Macksburg 500 foot sand, although the top of the former is 643 feet below the Pomeroy coal, while the top of the latter is only about 560 feet. There is also a great difference in the thickness of the rock at the two points, it being from 50 to 100 feet at Cow Run, and from twenty-five to feet fifty at Macksburg. It is one of the Lower Coal Measure sandstones, and lies very nearly midway between the Ames limestone and the top of the Cuyahoga shale.

The Perkins well gave an impetus to business which soon enabled the Bergen Company to dispose of all its two-acre lots at one-third royalty.

In 1867 the Exchange Oil Company, of Cincinnati, Ohio, was organized with a capital stock of $500,000, to develop territory purchased by it from Col. John H. Weare and others, adjoining the Bergen Company lands. The purchase gave the Exchange Company the southeast quarter of section 20, and the northeast quarter of northeast quarter of section 19, the remainder of northeast quarter of 19 being owned by Philip Geisse, of Wheeling, West Virginia. Thus the south half of section 20 and the north half of section 19 became the property of three parties—The Bergen, The Exchange, and Philip Geisse, and these two half sections cover substantially the whole of the Cow Run oil field.

The production was soon large enough to justify the laying of a transportation line, and in the spring of 1868 one was laid by the West Virginia Transportation Company, of Parkersburg, to the Ohio River 5½ miles distant. The pipe was two inches in diameter, which proved amply sufficient to carry the entire production of the field. The point of delivery on the river was three miles below Newport, and the oil was carried thence in bulk-boats to the refineries at Marietta and Parkersburg. The first iron tank of any size used in the state, for the storage of petroleum, was built by the "Cow Run Iron Tank Company," at the river terminus of the pipe-line. Its capacity was 10,000 barrels, and it was manufactured by James Riter, of Allegheny City, Pennsylvania.

The subject of drilling for deeper oil came up in due course of time, and although no one had any very definite working hypothesis to offer, talk was soon followed by action. Some five or six wells in different parts of the field, which were dry in the 600-foot sand, were sunk deeper as test-wells. Only one of them, however, was drilled deep enough to reach the Macksburg lower (Berea) sand. This was a well drilled by Col. John H. Weare, on the Exchange Company's property, to a depth of 2,100 feet. It should have reached the Berea sand at about 1,600 feet, but no record of the well was preserved, the

samples were lost, and it is now impossible to obtain any authentic information concerning the strata passed through. A well drilled last year (1884) by Mr. Chas. J. Garvey, on the northwest quarter section 24, Eight Mile Run, in Newport township, located about one mile south of the Cow Run field, seems to indicate a thinning out of the "Berea" in this part of Washington county. This view is further supported by a well just completed (1885) by Messrs. Whitney & Morton, near the southwest corner of section 16, Lawrence township, about two miles north of the Cow Run field.

Both of these wells report the "Berea" not found at its proper horizon.

PRODUCTION OF COW RUN FIELD.

Shallow wells (140-ft. sand), from 1861 to 1867; estimated					50,000 barrels.
Wells in both 140-ft. and 600-ft. sand, Jan., 1867, to Aug., 1868; est'd					150,000 "
West Va. Transportation Co. Runs,			1868 and 1869	89,571	
"	"	"	1870	110,412	
"	"	"	1871	46,543	
"	"	"	1872	39,456	
"	"	"	1873	35,016	
"	"	"	1874	31,990	
"	"	"	1875	26,606	
"	"	"	1876	20,427	
"	"	"	1877	21,461	
"	"	"	1878	22,929	
"	"	"	1879	22,370	
"	"	"	1880	20,655	
"	"	"	1881	16,944	
"	"	"	1882	12,682	
"	"	"	1883	14,166	
"	"	"	1884	8,291	
Ohio Transit	"	"	1885	12,000	551,519
Total					751,519 barrels.

The surface show of oil in the sand-rock (No. 10) on the land of John M. Rounds, northeast quarter of section 12, Newport township, caused considerable money to be spent in drilling upon the head-waters of Newell's Run prior to 1865, but nothing of real value was found. In 1865 the Bergen Company located a well upon the Joseph Brown farm at the mouth of the run. At a little over 400 feet, a fine showing of oil was struck in the Macksburg 300-foot sand. The well was tubed, and about 100 barrels of oil were pumped out, when the supply seemed to be exhausted. It was not properly cased, and was thought to have been spoiled by caving in of the walls. Three other wells were afterwards drilled near by, on the same farm, but none of them revealed the lost vein. One of the latter was drilled to 1,030 feet, and stopped in the salt-

water sand. The writer afterwards superintended the drilling of 4 other wells through the Cow Run 600 foot sand, near the mouth of Newell's Run, and in every case the rock was found to be filled with brine instead of oil.

On Northrup's Fork of Newell's Run, in Section 10, Newport township, some wells have yielded from 2 to 5 barrels per day from the first run. These wells are located on the western slope of the White Oak anticlinal, which crosses the Ohio river near the mouth of Newell's Run. (See Profile No. 2)

Prior to 1885 there had been no wells drilled on Newell's Run deep enough to reach the Berea sand; the one on the Brown farm (1,030) being the deepest. This year (1885) a well was drilled by Joel Bigham & Co., of Pittsburgh, on the Gilman farm, about one mile west from the mouth of Newell's Run. The well-head is near the level of the Meigs Creek coal. At about 1,700 feet the "Berea" was found, with a reported thickness of twelve feet, and was said to contain a little oil. It was torpedoed, but failed to flow, and would not pay to pump. A second well was drilled by the same parties on the Tucker farm, southwest quarter of Section 5, Newport township, about one and one-half miles north from the mouth of Newell's Run. The well-head is eighty feet below the Meigs Creek coal, and the "Berea" was found at a little over 1,600 feet, with a thickness of eight feet; it was torpedoed, but failed to produce any oil. Both of these wells were worked as "mysteries" by their owners, but the above statements may be safely considered as substantially correct.

The Macksburg Oil-Field 1872 to 1878.

While work was being prosecuted vigorously at Cow Run, operations at Macksburg were almost entirely suspended. A few of the old wells were pumping a little oil, but no new ones were either started or contemplated. Matters remained in this condition until 1872, when a survey was made in the interest of Mr. George Rice, then engaged in the producing business of Burning Springs, W. Va. The object of the survey seemed to be to start at Burning Springs and run a line through the producing districts at West Virginia and Ohio, taking the courses and distances of the producing wells, making a single map of the whole. The line ran from Burning Springs through Oil Rock, White Oak and Horseneck, the producing districts of West Virginia, crossed the Ohio at the mouth of Newell's Run, and there, changing to a northwesterly course, ran through Cow Run, Fifteen Mile and Pawpaw Creek to Macksburg. Finding the well that was drilled in 1865 upon the Lowell Oil Co. tract, still pumping about five barrels per day from the 500-foot

sand, Mr. Rice purchased the tract, cleaned out and torpedoed the old well, and brought its production up to fifty barrels per week. In the meantime the Cleveland and Marietta Railway had been completed through the Duck Creek Valley, making Macksburg a more desirable field for operations than it had been in its early days. In 1874 Mr. Rice was drilling his well No. 4, when, at 140 feet, a vein of oil was struck, which, when tested, started off at 150 barrels per day. This unexpected strike soon drew the attention of operators from Cow Run, which was then on the decline, back to Macksburg. From 1874 to 1877, the close of the period now under review, the following wells were drilled on Goose Run, a tributary emptying into the West Fork of Duck Creek at Macksburg:

On Lowell Oil Co. tract, Geo. Rice, No. 4, 140-ft. sand—150 barrels.
" " " " No. 5, in 500-ft. sand—small well.
" " " " No. 6, in 300-ft. sand— "
" " " " No. 7, through 500-ft. sand—dry.
" " " " No. 8, in 500-ft. sand—small well.
" " " " No. 9, through 500-ft. sand—dry.
" " " " No. 10, in 500-ft. sand—small well.
" " " " No. 11, " " "
" " " " No. 12, " " "
" " " " No. 13, " " "
" " " " No. 14, through 500-ft. sand—dry.

Chas. Egler tract, Marietta O. Co., No. 1, in 140-ft. sand—first day, 500 barrels.
" " " " No. 2, in 500-ft. sand— 10 "
" " Decker & Sons, No. 3, in 300-ft. sand— 10 "
" " " No. 4, through 500-ft. sand—dry.
" " " Nos. 5 and 6, through 500 ft. sand—dry.
" " Dexter City O. Co., No. 1, in 500 ft. sand—small well.

E. F. Atkinson tract, Biszantz Co., No. 1, in 140-ft. sand—small well.
" " " No. 2, in 500-ft. sand— "
" " " No. 3, through 500-ft. sand—dry.
" " " No. 4, " " "
" " Jno. Hamilton, No. 1, " " "
" " Barton & Stevens, No. 1, in 500-ft. sand—small well.
" " " No. 2, " " "
" " " No. 3, through 500-ft. sand—dry.

Dyer tract, Wilson Staats, No. 1, through 500 ft. sand—dry.
" " Stephen Hobbs, No. 1, " " "
Davis tract, H. B. Iams, No. 1, " " "

On Duck Creek Valley, below Macksburg:

A. T. Warren tract, Wilson Staats, No. 1, through 500-ft. sand—dry.
Jno. Smithson tract, Jas. Kennedy, No. 1, " " " "
" " Decker & Sons, No. 1, " " " "
I. Delong " " " " " " "
New Jersey " " " " " " "
" " " No. 2, " " " "

The small wells above noted were under ten barrels per day, and the large ones in the 140 foot sand, in the summer of 1876, had dwindled to small dimensions; this, with the large percentage of dry holes, made a rather discouraging outlook for the field.

In 1872, William Snodgrass took a lease on the Leonard Britton farm, at the mouth of Mill Fork of Fifteen Mile Creek, in Lawrence township. At about 400 feet a ten-barrel well was obtained in the black shale, between the first and second Cow Run sands. This was soon followed by the Lackey well, on the same farm, which started at fifty barrels per day; then the Schnaufer well on the Rathbone tract, southeast of section 23, fifty barrels per day; and the Perkins & Co. well on the Skinner tract, southwest of northeast section 23, ten barrels per day. These wells all obtained their oil from the shale and were soon exhausted. In the following year were drilled:

On Britton tract, Snodgrass No. 2, through 600-ft. sand—dry.
On James Cuthbert tract, School-house Co. No. 1, through 600-ft. sand—dry.
On N. Kennedy tract, Cuthbert & Carle, No. 1, " " "
On Rathbone & Co. tract, Weare & Co., No. 1, " " "

This, it was at first supposed, would prove to be a northern extension of the Cow Run field, but the above wells, which passed through the second Cow Run sand without finding oil, discouraged further attempts in that direction.

In 1877, another attempt was made to strike the Cow Run "belt" about half-way between Cow Run and the mouth of Mill Fork. The same party, Mr. William Snodgrass, leased a part of the John Myers farm near the mouth of Morse Run, in southwest corner of section 21, Lawrence township. A ten-barrel well was found in the first Cow Run sand. Some ten or twelve wells were subsequently drilled through this sand, along the bed of the run in section 21, none of which obtained oil in paying quantity. All attempts thus far to find an outlet to the Cow Run pool of shallow oil, have been unsuccessful. The productive territory appears to be confined to the crest of a small anticlinal in sections 19 and 20, Lawrence township. The shape and extent of the uplift, and the position of the productive wells, is shown by the accompanying cross-sections.

In the summer of 1877, an attempt was made to extend the Macksburg field in a northerly direction, by drilling a well for the 500-foot sand on Buffalo Run. Some years before, a well had been drilled on the Slaymaker farm, on this run, which made a fair showing of oil that was supposed to come from the 500-foot sand. The well had been abandoned by its owners, but the oil continued to rise through the water in the

well and accumulate in the conductor, from which it was dipped and carried away in jars by the natives as a cheap lamp-oil.

The gentleman who first proposed the venture was a Mr. Williams, of Dexter City. Not having sufficient capital to carry out his plan, he made the following proposition to the writer: "To any one who would furnish the use of machinery, tools, and casing to drill the well, he would give one-fourth of the oil obtained; machinery, tools, and casing to be returned in good order, ordinary wear excepted, if no oil obtained." Parties were found who accepted this proposition, and Mr. Williams commenced operations. The location chosen by him was on the bed of Buffalo Run, Matthew Mitchell farm, which lies just below the Slaymaker tract. Mr. Williams was afterwards joined by Capt. Mosely, and the well was sunk by them to a depth of 800 feet, without obtaining oil in paying quantity. These particulars are given at some length, because this is the well by which the existence of the "Berea" sand in the Macksburg field was proven. After Messrs. Williams and Mosely had abandoned the well, the parties who owned the machinery and tools were persuaded by the writer to drill it down in search of the "Berea," which was then yielding oil in the White Oak district of West Virginia. Careful measurements of the interval between the Ames or crinoidal limestone, and the "Berea," had been made in the West Virginia field, where it was found to be about 1,400 feet. The position of the "Ames" at Buffalo Run, was known, by him, to be about seventy feet below the bed of the river on the Mitchell farm. It was, therefore, decided to drill the well to a depth of 1,500 feet, if the rock should not be found at a less depth. The interval at Macksburg proved to be somewhat less than at White Oak, and the top of the sand was struck at 1,427 feet. The well was drilled wet and was standing full of salt-water; when the first bit was run in the sand it began to show gas, and the second bit developed enough gas to throw the column of brine over the top of the derrick and empty the well. In order to complete the well it was necessary to place an oil-saver upon the casing-head to prevent the driller being pickled. Below the gas a thickness of fifteen feet of very fine white sand, containing the "rainbow colors" of petroleum was found. The well was tubed with packer and two-inch pipe, but yielded nothing but dry gas. It was never torpedoed. The odor of the gas was exactly like that of petroleum, but this and the colors were the only evidences of the propinquity of this venture to the richest portion of the Macksburg field.

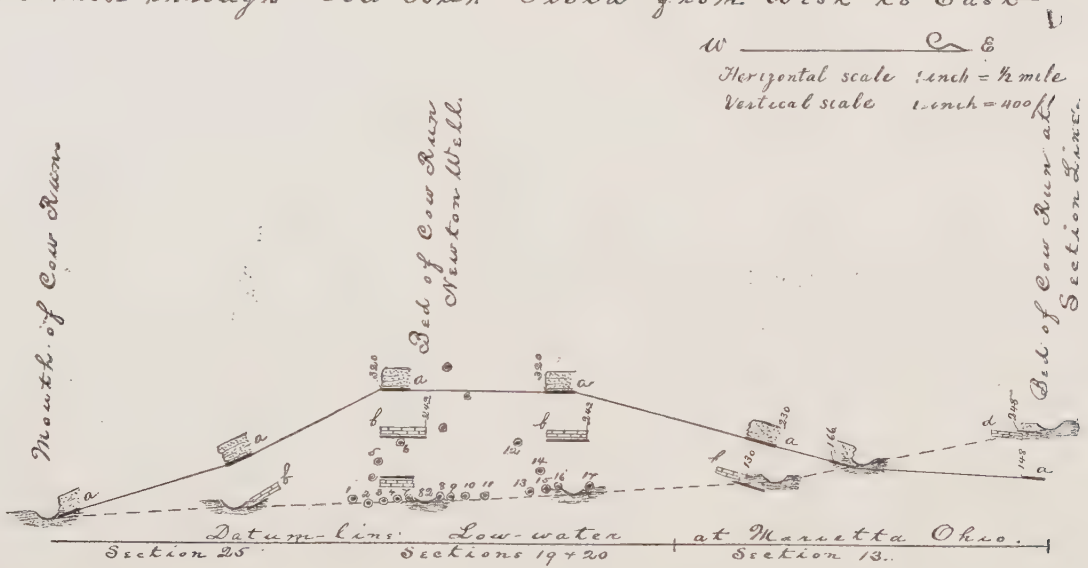
From the foregoing facts it will be seen that geological considerations had nothing to do with the *location* of the well, but that the search for, and discovery of the "Berea," as an oil-producing sand in the Macks-

Section through Cow Run Field from North to South

Horizontal Scale 1 inch = ½ mile
Vertical Scale 1 inch = 400 ft

1 Mulberry Well
2 Montana "
3 Blauvelt & Co "
4 Cherry "
5. New Jersey Well
6 Flanders "
7. Perkins #1 "
8 Mt Vernon #2 "
9. Breech-tree Well
10. Grecian-bend "
11. Nigans No 2. "
12. Log-cabin "
13. Hope Well
15. Sams & Co "
16. Comet "

Section through Cow Run Field from West to East


W
E
Horizontal scale 1 inch = ½ mile
Vertical scale 1 inch = 400 ft
Mouth of Cow Run
Bed of Cow Run Newton Well.
Bed of Cow Run at Section Line.
Datum-line: Low-water at Marietta Ohio.
Section 25
Sections 19 & 20
Section 13.

1. Ajax Well
2. Perkins No 2 "
3. School-house "
4. Perkins No 1. "
5. Grecian-bend "
6. Beech-tree Well
7. Newton "
8. Warren "
9. Elephant "
10. Blue bird "
11. Elm-tree Well.
13. Willow "
14 Home "
15. Wrase Deep "
17 Exchange No 7 "

a. Macksburg Coal
b. Meigs Creek "
c. Pomeroy "
d. No 11 Limey "

burg field, were due to those simple inferences from carefully observed facts concerning the order and relation of strata in the earth's crust which form the elementary principles of the science called Geology.

The Great Development 1878 to 1885.

In the fall of the year 1878, Mr. George Rice decided to put his well, No. 14, which had missed the 500 foot sand, down to the level of the sand found in the Buffalo well, for the purpose of obtaining gas to use as fuel in working his shallow wells. The well was completed in the following year; the sand was found at its proper horizon; gas enough to run the shallow wells was obtained, and about fifteen barrels per day of amber-colored oil of 39° gravity. The well was tubed with water-packer, and flowed instead of waiting to be pumped.

It is now difficult to understand why this result attracted so little attention. It is true the well was small, and the drilling somewhat tedious on account of the large body of brine, between 900 and 1,100 feet, calling for the latter amount of casing if one wished to carry his well through the oil-sand dry. At any rate, no other wells were started until 1881, when Messrs. Heiner and Pershing drilled on the Lund farm, which adjoins Mr. Rice's tract. This well found the sand, and a large flow of gas with very little oil; it showed no improvement after being "shot" with 100 pounds of Hercules powder, and was abandoned.

The next venture was made by a Mr. Smith, on the Jersey farm (Jacob Dearth's) in 1882, and in the same year Mr. Hulings commenced operations on the A. Perkins farm, and Decker & Sons on the Wm. Atkinson farm. Mr. Smith's well produced about three barrels per day, Mr. Hulings', eight barrels, and Decker's, twelve barrels. This was the sum total of operations in 1882. In the following year, Messrs. Laing & Co. drilled on the Ohio Coal Co. lands, and obtained a well which started at 100 barrels per day, and at once attracted the attention of Pennsylvania operators. The following list shows the principal operators in the Macksburg field, besides those above mentioned:

Laing & Keeler, Smithson farm and Delong farm.
Mills & Mullen, Clark farm, G. Stevens and Patton farms.
W. B. McManus, Roff farm.
St. James Oil Co., James Farm and Shaw farm.
Borkman & Laney, Jersey farm, Clinedenst and Perkins farms.
Weaver & Co., McClouth farm.
Clark & Whitney, A. Warren farm and W. Atkinson farm.
C. M. Payne, T. George farm and Shilling farm.
Bess Brothers, Smith Dutton farm.
Union Oil Company, Williams farm, McGinnis farm, Hupp farm.

Bradley & Lockwood, Duvall farm, Stone farm.
Anchor Oil Company, M. Shilling farm, G. Hupp farm.
C. J. Garvey & Co., F. Perkins farm, Clinedenst farm.
Charles Lineman, F. Perkins farm, Osborne farm, Coffee farm.
R. H. Lee, Ohio Coal Co. lands.
Theo. Barnsdall, Hupp farm, Merrill farm, Morris farm, Deal farm, Phelps farm, W. Warren farm.
Boden & Aiken, B. F. Atkinson farm, Dyer farm.
John Denman, W. Warren farm, Gordon farm, Shilling farm, Finch farm, Patton farm.
Stevens & Longfellow, B. F. Atkinson farm.
Gilmore & Porter, Davis farm, Wiper farm, J. Kellar farm.
McConnell & Penwell, Egler farm.
Willis Decker, Decker farm.
Clark & Spellacy, Clinedenst farm.

Transportation.

Prior to November, 1883, there were no pipe-lines in the Macksburg field. Mr. George Rice and Messrs. Decker & Sons had arrangements of their own for filling oil into tank-cars of the Cleveland and Marietta Railway.

In the winter of 1883, lines were laid for conveying the oil from the field by the "Ohio Transit Company," which was duly incorporated in the following April with a nominal capital of $250,000, by T. D. Dale and others, of Marietta, Ohio. Arrangements were made by the company with the C. & M. R'y to carry the oil over its road in tank-cars owned or leased by the company. Nearly all of the shipments made from the field during the year 1884, except Mr. Rice's production, went through the Ohio Transit Company's lines.

In the summer of 1884, a line was laid from the field to a point on the Muskingum river near Lowell, by "The West Virginia Transportation Company," of Parkersburg.

Immediately following the completion of this line, "The National Transit Company" commenced building iron storage tanks in the field, and purchasing the oil at a premium. In the spring of 1885, "The National Transit" purchased the two competing lines, and laid a three-inch line of its own from the field to Parkersburg, W. Va., which is known as "The Macksburg Pipe Line". Since the completion of the National line, Mr. George Rice has laid a two-inch line from the field to a point on the Muskingum River near Lowell, through which he ships the oil produced and purchased by himself. The following statement of production is furnished by Mr. D. J. O'Day, Superintendent of the "Macksburg Pipe Line."

MACKSBURG, OHIO, *March* 30, 1886.

F. W. Minshall, Esq., Parkersburg, West Virginia:

DEAR SIR: Below find close estimate production of the Macksburg field from August, 1884, to February, 1886:

August, 1884	4,600	barrels.
September, 1884	5,071.82	"
October, 1884	6,949 90	"
November, 1884	9,312.69	"
December, 1884	10,055.27	"
January, 1885	12,894.13	"
February, 1885	21,625.25	"
March, 1885	28,067.39	"
April, 1885	42,227.02	"
May, 1885	48,957.81	"
June, 1885	66,181.94	"
July, 1885	79,736.57	"
August, 1885	76,228.03	"
September, 1885	72,110.13	"
October, 1885	69,618 92	"
November, 1885	67,926.05	"
December, 1885	66,175.80	"
January, 1886	61,926.44	"
February, 1886	57,682.91	"

Respectfully yours,

D. J. O'DAY, *Superintendent.*

In defining the limits of the field, the following dry wells were found:

No. 1. F. W. Minshall, one on M. Mitchell farm—gas.
No. 2. Heiner & Pershing, one on Lund farm—gas.
No. 3. St. James O. Co., one on Eagle Oil Association farm—gas.
No. 4. St. James O. Co., one on R. K. Shaw farm.
No. 5. Bradley & Co., one on Hall farm.
No. 6. Nesbitt & Co., one on J. Schram farm.
No. 7. Brown & Co., one on M. True farm.
No. 8. Bradley & Lockwood, one on Linscomb farm.
No. 9. Clark & Whitney, one on Armstrong farm.
No. 10. Mills, one on Morris farm.
No. 11. Mills & Mullen, one on Schilling farm.
No. 12. Union Oil Co., one on Huddleston farm.
No. 13. Union Oil Co., one on Neptune farm.
No. 14. Theo. Barnsdall, one on Otter Slide farm.
No. 15. Gilmore & Porter, one on Mosher farm.
Nos. 16 and 17. Gilmore & Porter, two on J. Kellar farm—gas.
No. 18. Gilmore & Porter, one on Wiper farm.
No. 19. Decker & Sons, one on Decker farm—gas.
No. 20. Bailey & Co., one on Jno. Kathary lot—gas.

The above wells are numbered and connected by lines upon the annexed map of the Macksburg field. The lines go entirely around the

field, and the space intervening will be measured by them on the scale of one mile to the inch.

The following dry wells have been drilled at other points to a depth sufficient to reach the Berea sand:

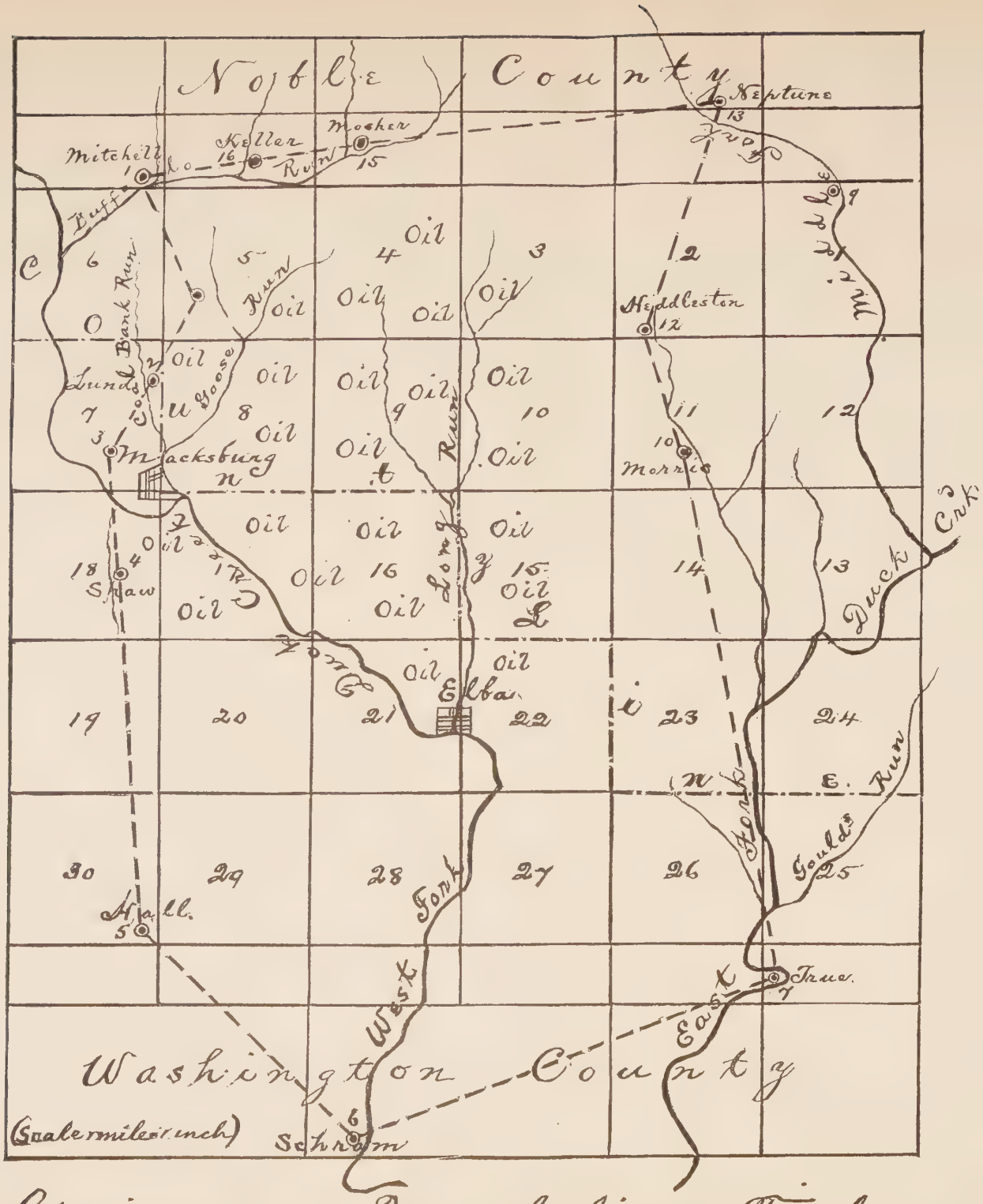
Dale & Co., one, Murgridge farm, near Dexter.
Dunn & Worrall, one, Noble county, near Dexter.
" " " near South Olive.
Pryor & Co., " " near Dudley.
Caldwell O. and G. Co., one, Noble county, near Caldwell.
Marietta Gas Co, one, Washington county, Marietta.
Bradish Oil Co., one, " Fifteen Mile creek—gas.
Whitney & Morton, one, " Covey farm.
" " " J. Rake farm.
Bigham & Co., " " F. Gilman farm.
" " " Tucker farm.

At Federal Creek, the following wells were drilled to the horizon of the Berea; in all of them a fair thickness of the sand was found, but it contained neither gas nor oil:

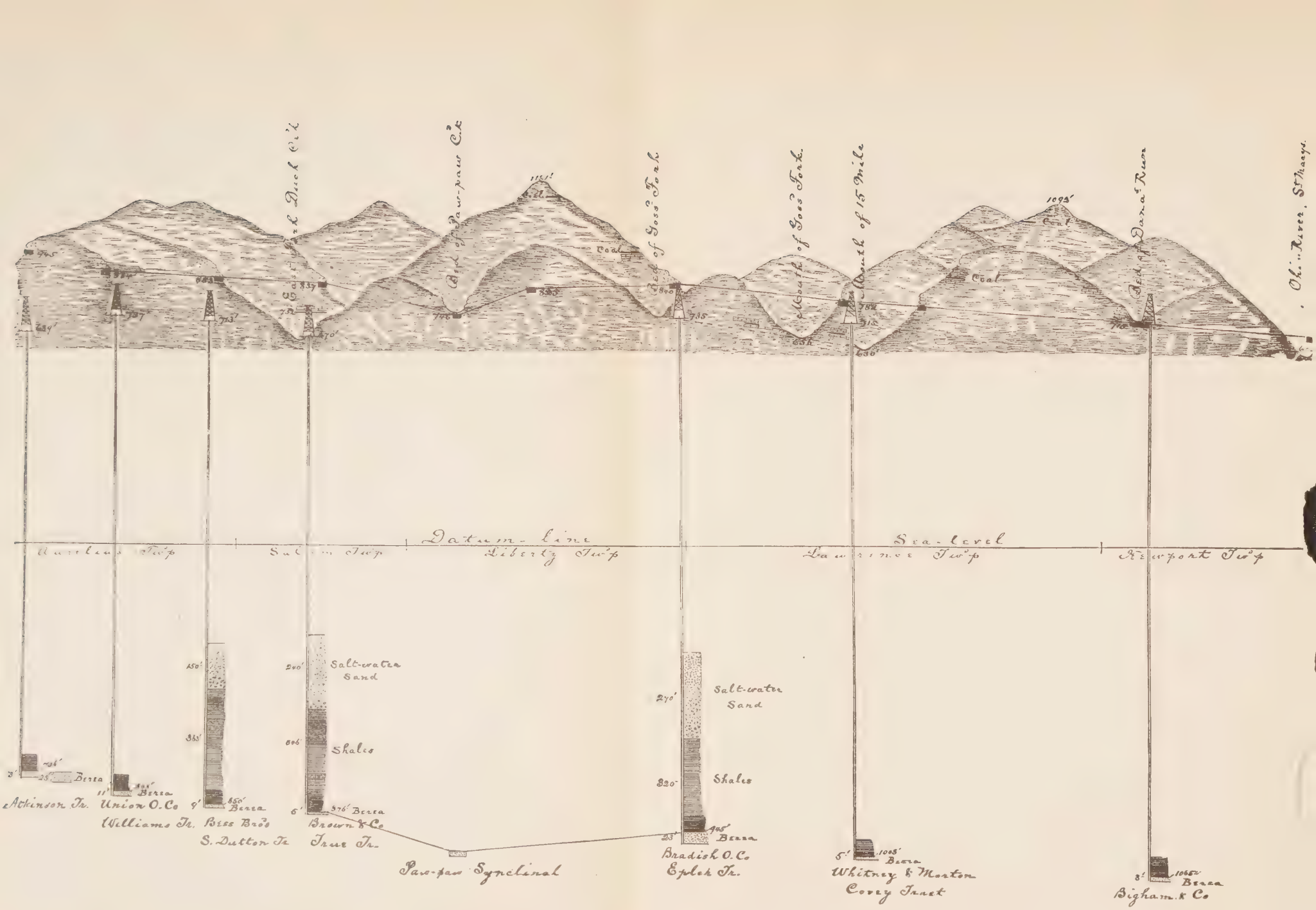
Dale & Co., one, Morgan county, Bishop farm.
Bradley, Laing & Co., one, Morgan county, Swayne farm.
Williams & Co., one, Morgan county, L. L. Joy farm.
Dale & Co., one, Athens county, mouth of Big Run.

Thus far all attempts to extend the Macksburg field, or to find another productive "pool" in the Berea sand, have been unavailing. The best indications are those found in the Bradish Oil Company well, on the C. F. Epler tract, in Liberty township. This well shows twenty feet of the Berea, with a strong flow of gas from the top of it, and the whole thickness saturated with the amber colored petroleum peculiar to it. The rock is rather firm in texture, but is a clear quartz sand, and is superior in quality and thickness to that found in the writer's well on the Mitchell farm, which opened the Macksburg field.

From the foregoing pages it will be seen that the search for petroleum in Washington county has been, in a great measure, confined to Aurelius, Salem, Liberty, Lawrence and Newport townships, and that more or less oil has been found in each one of them. The drilling was caused by surface indications in each township, viz.: Oil on the surface of Duck Creek, at James Dutton's, in Aurelius; oil on Pawpaw Creek, in Salem; a burning gas-spring on Mill Fork of Fifteen Mile Creek, in Liberty; a burning spring on Cow Run, in Lawrence, and oil in the sandrock in bed of Newell's Run, in Newport. In each case the development extended from the starting point along the beds of the several streams, and no drilling was done upon the uplands until the derricks began to



Limits of Macksburg Field defined by dry wells drilled.



Section from Macksburg to Ohio River at St Mary's, from N.W. to S.E. Horizontal scale 1 inch = 2 miles
Vertical scale 1 inch 400 ft

climb the Cow Run hillsides in 1869. In the Macksburg field no drilling was done on the hill territory prior to 1881. Not even the ghost of a geological theorist was seen or heard by the practical operator prior to 1870. Wells were located, sometimes with a peach-tree fork in the hands of an oil-wizard, at other times "Aunt Judy," a colored fortune-teller, of Marietta, was called upon to designate the lucky spot. Others still put faith in a small phial of oil suspended from a switch in the hands of the wizard, while the majority went in "blind," and trusted to luck. In 1870 it was discovered, by drilling all around the Cow Run field, that the productive territory was confined to the crest of a small anticlinal. It was also discovered that the productive territory at Horse-neck, White Oak and Burning Springs, in West Virginia, was similarly situated. Since then attention has been directed to the contour of the surface-rocks, as well as to surface-shows of oil, in seeking new fields. The surface-shows in the townships above-named would be covered by a comparatively narrow belt running in a northwesterly direction from the mouth of Newell's Run, on the Ohio River, to Macksburg. Oil-belts, however, being credited by Pennsylvania operators with having a predilection for a northeasterly course, the attention of those having faith in "belt" theories has not been attracted by this fact. For the purpose of showing, in a general way, the contour of the rocks in the townships above-named, a series of levels was run and the results are shown in the annexed profiles. (Section from Macksburg to Ohio River.)

Line No. 1 commences at Dexter City station on the C. & M. railway, and running a southeasterly course crosses Goose Run at the residence of B. F. Atkinson, thence across lands of said Atkinson, F. Perkins, Lee & Apple, McGinnis and Ohio Coal Company, to Long Run. Crosses Long Run above residence of G. W. St. John, runs thence across lands of S. W. Dutton, Sam'l Still and others, to East Fork of Duck Creek. Crosses East Fork at mouth of Gould's Run, in Salem township, runs across lands of M. True near Brown & Co test-well, thence to Pawpaw Creek. Crosses Pawpaw at mouth of Cline's Run, in Liberty township, thence up right-hand fork of Cline's Run across lands of G. C. Best and others, into the head of Goss's Fork of Fifteen Mile Creek; thence down Fifteen mile to its junction with the Little Muskingum River, in Lawrence township; thence to mouth of Bear Run, and up the run to its head; thence over the ridge by Pine Grove church and across lands of A. Shafer and others, into the head of Dana's Run; thence down Dana's Run to Milltown and across lands of S. Dana and others to the Ohio River opposite the mouth of Middle Island Creek.

No. 2 runs parallel with No. 1, and about two miles to the southwest of it. Beginning near the head of Sugar Run, at Jacob Baker's west line in Lawrence township, it runs over the ridge into the head of Baker branch of Morse Run; thence down the run to its junction with the Little Muskingum River; crossing the river it runs over the ridge across Section 20 into Cow Run, up Cow Run to its head, and over the ridge into Newell's Run, thence down Newell's Run to mouth of Kerr's branch, thence over the hill across lands of L. Rowland, A. Friedle and E. Buttelle to Ohio River, one mile below Newport.

These two lines show three well-marked anticlinals, which may be designated the Liberty, the Lawrence and the Newport arches.

Line No. 1 crosses the Liberty arch about one mile southwest of its highest point (as shown in No. 3). It crosses the extreme northern end of the Lawrence and Newport arches where they are only indicated by the dip on the southeast side of the Newport one. Line No. 2, however, shows the southeast dip of the Liberty arch, crosses directly over the crest of the Lawrence, and also over the Newport axis at its highest point in Ohio. The Newport is the northern extension of the White Oak anticlinal, and profiles Nos. 1 and 2 show how rapidly it is flattening out to the northeast. Line No. 3 begins at Marietta, runs in a northeasterly direction to the mouth of Sugar Run, in Fearing township; thence up Sugar Run to its head, and across the head of Mill Fork to Goss's Fork of Fifteen Mile, where it crosses Line No. 1 on lands of C. F. Epler; thence, running with the strike of the Liberty arch, crosses Dean's Fork on lands of E. Schwarz, Sycamore Fork on lands of A. Smith, main fork of Fifteen Mile, on lands of William Roberts, and East Fork on lands of Jacob Schenkel; thence over the ridge into the head of Whitten Run in Monroe county, and down Whitten two miles to forks of the run.

The profiles show 1st, a dip southeast from Goose Run, in the Macksburg field, to the bottom of the Pawpaw synclinal of 200, feet as measured on coal No. 10. 2d. On the Liberty arch a northwesterly dip of 114 feet to bottom of Pawpaw synclinal; a southeasterly dip of 187 feet to Ohio River at mouth of Middle Island Creek; a southwesterly dip of 307 feet to the mouth of Sugar Run, and a northeasterly dip of seventy-one feet to the forks of Whitten Run in Monroe county, as measured on coals Nos. 10 and 11. 3d. On the Lawrence arch, a northwesterly dip of 200 feet to the bottom of the Morse Run synclinal, a southeasterly dip of 172 feet to head of Cow Run, as measured on coals Nos. 9, 10 and 11. 4th. On the Newport arch, a northwesterly dip of 270 feet to head of Cow Run, and a southeasterly dip of 305 feet

to bed of Green's Run in West Virginia, opposite Newport, Ohio, as measured on coals Nos. 9 and 10.

In the test-wells drilled along Line No. 1, it was found that the dip of the Berea sand does not exactly coincide with that of the upper coal veins; this variation is caused by a thickening, to the southeast, of the rocks lying between coal No. 10 and the Berea. At Macksburg this interval, as shown at well No. 1 in the figure, is 1,681 feet; at No. 2, 1,687 feet; at No. 4, 1,713 feet, and at No. 5, 1,790 feet, where the interval appears to reach its maximum, which it very nearly maintains to the Ohio River.

The position of the Berea in the Pawpaw synclinal is estimated by averaging the interval between wells No. 4 and No. 5. In the drawing the figures at the top denote the height of the respective points above sea-level; those at the bottom show how many feet the top of the Berea sand lies below sea-level.

The high point indicated in the figure as the site of the "Gruber church," is 2,106 feet above the Berea sand. This may be taken as the greatest depth it will be necessary to drill for the Berea from the highest points in any of the townships through which Line No. 1 passes. By means of the bench marks along the lines of the survey, and the figured depth of the Berea below sea-level, it will be an easy matter to estimate pretty closely the depth to the sand from any point in this part of Washington county.

Natural Gas in the Macksburg Field.

Since the application of natural gas to manufacturing purposes as a fuel that may be cheaper and better than coal, when found within reach of the larger towns, a large gas-well may have an economic value equal, if not superior to that of an average oil-well. There is always more or less gas found with the petroleum in an oil-bearing rock. In the deeper wells the quantity of gas is sufficient to throw the liquid petroleum out of the well through the tubing. The gas is therefore constantly issuing from the flowing wells, and it is carried in pipes to the furnaces of the drilling wells. After the first flowing well is obtained upon a tract the succeeding wells are usually drilled with very little, if any, expenditure for fuel. When more gas is obtained than is necessary for drilling purposes, the surplus is carried into the houses and used for both heating and lighting them. Most of the towns in the immediate vicinity of the several oil-fields are now fully supplied with gas for domestic use, and large quantities escape and are wasted. In prospecting for oil it frequently happens that at some points the oil-bearing stratum is completely filled with an accumulation of gas having a high tension. In such wells the natural pressure of the gas is suffi-

cient to force it through mains to towns several miles distant. A few wells of this kind have been found in the course of development described in the preceding pages. The first one was drilled by Mr. John B. Kigans, in 1870, in the Cow Run field, on the crest of the Lawrence township anticlinal. The well went through the 600 foot sand dry, and was put down for a deep test-well. It was located on the hillside, about 100 feet above the Meigs Creek coal; at 1,200 feet a heavy vein of gas was struck in the top of the salt-water sand. The flow of gas was so strong that it was not thought possible to drill it any deeper, and it was abandoned. In 1878, the well heretofore described as the first one drilled into the Berea at Macksburg, on Buffalo Run, struck a strong flow of gas in the top of the sand. Since the development of the Macksburg field, several similar wells have been discovered.

Relative Positions of Gas and Oil.

The annexed map shows the relative position of the gas-streak to the best productive oil territory in the field. All the wells on the northwest side of the line have strong gas and little or no oil. The figures enclosed in rectangles show the depth at which the top of the Berea is found in the respective wells.

The well lately drilled by the Bradish Oil Company (1885), on the C. F. Epler farm, Fifteen Mile Creek, is located on the crest of the Liberty township anticlinal. It has a strong flow of gas and very little oil from the Berea sand. It is the only well drilled, as yet, on the crest of this arch. The well is about eleven miles distant from Marietta, and seems, thus far, to promise the nearest available supply for that city. A well lately completed by Messrs. Whitney and Mort n, on the Jacob Rake farm, northeast quarter of section 10, Lawrence township, found a strong flow of gas in the second Cow Run sand, but nothing in the Berea. The Marietta Natural Gas Company, also, found a considerable vein of gas in their well now drilling on the C. Cherry farm, in Fearing township.

Refineries of the Field.

In 1861, Mr. Jonathan Hoff finding no sale for the oil from his Cow Run well, occasionally drew a wagon load to Marietta, and left it in store with R. P. Iams & Company. About 100 barrels of it had accumulated in their hands in this way, when it was purchased by W. L. Greenhill, at nine cents per gallon. It was put into a flat-boat by Mr. Greenhill and poled up the Muskingum River to Zanesville, Ohio, where Mr. Matthew Hodkinson had erected a small refinery for the purpose of purifying the coal-oil then being manufactured at Newark, Ohio. Mr. Greenhill succeeded in exchanging his crude petroleum with Mr. Hod-

Relative positions of gas and oil in the Macksburg Field.
St James Oil Co.
Decker Gas
St James Gas
Bailey Gas
Stevens
L. Macksburg
McManus
Cool Bank
Weiner Gas
Decker
Creek
Rice
Borkman and Laney
George
Run
Gilmore Gas.
Gilmore Gas
Clark
Whitney
Boden
Gordon
Old
Macksburg Oil Co
Borkman Laney
Lineman
Aiken
R H Lee
C. Lineman
Ohio Oil Co
Union Oil Co.
Anchor Oil Co
Long Run
Ohio Oil Co.
Jno Denman
Buffalo
Minshall Gas.
Gilmore Gas
Run
Gilmore Gas

kinson for refined oil, which he put into his flat and pushed back to Marietta. Soon after this transaction Mr. Hodkinson came to Marietta, and, in company with his sons, built a refinery in the upper end of the city, on the bank of the Muskingum River. The original plant contained three stills of about forty barrels capacity each. The works were ready for operation in 1861.

In the same year, Dr. J. C. Herring built a small refinery on the upper end of Greene street. His first still was made from an old stoam-boiler; he afterwards put in a new still of sixty barrels capacity. Mr. C. F. Buell became a partner, and the business was carried on under the firm name of Herring & Buell until 1865. An unfortunate contract made in that year for the product of the Newton wells for a year; at $12.00 per barrel at the well, caused the firm to suspend business.

The third refinery built was that of Messrs. McAllister and Greenhill, on the Newport turnpike, about two miles from Marietta. This was built about 1861–2, and contained one still of fifty barrels capacity.

The next was that of Messrs. Greenhill & Hodkinson, on Third street, between Greene and Ohio streets; one still, capacity eighty barrels.

In 1863–4, Messrs. R. P. Iams & Son put up their works, corner of Second and Montgomery streets, Marietta. Started with one still of sixty-five barrels capacity, afterwards put in one of 125 barrels and one of 150 barrels capacity.

In the same year, Messrs. Greenhill & Hodkinson removed their works from Third street to the mouth of the Little Muskingum River, four miles above Marietta. These works afterwards passed into the hands of Curtis, Newton & Co., and finally came into the possession of O. M. Lovell & Co., by whom they have been run successfully for several years as the "Phœnix Oil Works." The original eighty barrel still was replaced by one of 250 barrels capacity, after the works came into Mr. Lovell's hands.

In 1864, a small refinery was built on the upper end of Greene street, in Marietta, by Mr. W. C. McCarty. The still had a capacity of seventeen barrels. The first lot of refined oil, eighty-five barrels, was shipped to Cincinnati, and sold for eighty-four cents per gallon. Mr. McCarty afterwards put in another still of fifty-barrel capacity. In 1872, the plant was moved to its present location, one mile below Harmar, on the bank of the Ohio River. The present still capacity is one fifty-barrel, one one hundred-barrel, and one two hundred and twenty-five barrel. The works are still run by Mr. W. C. McCarty & Son, and are known as the "Marietta Oil Works."

In 1875, Mr. C. K. Leonard began building a refinery alongside the C. & M. Railway, on the outskirts of Marietta. In the following year these works came into the possession of George Rice, Esq., who put in two stills of one hundred barrels each. He has since added one of three hundred barrels, and another of six hundred barrels capacity, making a total of 1,100 barrels still capacity; being known as "The Ohio Oil Works."

In 1876–7, R. P. Iams, Theodore D. Dale, and others, built what is now known as "The Argand Oil Refinery," on the bank of the Ohio River, about one mile below Harmar. The original plant contained three small stills, of about thirty-five barrels capacity each, brought from the old refinery of White, Hook & Co., at Stockport, Ohio. These small stills have since been replaced by one of sixty-five barrels, one of one hundred and twenty-five barrels, and one of one hundred and seventy five barrels capacity.

In 1881, Mr. Richard Patton started the manufacture of cold test lubricating oils at the lock-factory building in Harmar. In 1882, the works were removed to a site on the C., W. & B. Railway. There were two stills of seventy barrels capacity each. Mr. Patton confined his attention to the manufacture of lubricating oils, using crude from the White Oak district of West Virginia. In 1884 the works were sold to the "Argand" Company.

In the present year (1885), Messrs. W. L. Greenhill & Co. have erected works at Marietta, for the manufacture of cylinder and engine oils, axle-greases and lubricating oils of all grades. They have not yet put in any stills, but contemplate doing so at an early day.

In 1861–2, a small refinery was built at McConnelsville, Ohio, and also one in 1865, at Stockport, Ohio, for the purpose of working the crude petroleum obtained from Buck Run and Federal Creek, in Morgan county. In 1876 the former was purchased and wrecked by the Camden Consolidated Oil Company, of Parkersburg, West Virginia, and the latter was purchased and moved, as above stated, by Messrs. Iams and Dale, to Harmar, Ohio. In the same year (1876), the Camden Company purchased the "Hodkinson" and the "R. P. Iams & Son" refineries, and removed the stills and machinery to Parkersburg.

The sources from which the early refiners drew their supplies of crude, between 1861 and 1866, were Burning Springs, on the Little Kanawha River; Horseneck, on the Virginia side of the Ohio River, nine miles above Marietta; Cow Run and Macksburg. From 1866 to 1876 the supply came chiefly from the 600-foot sand of Cow Run, and the 140 foot sand of Macksburg. Between 1876 and the development of the "Berea" sand at Macksburg, the refiners, especially Mr. Rice, fre-

quently had to go to Pittsburgh for crude. Now, the Macksburg field yields sufficient to supply all of the refineries at Marietta and Parkersburg, and still has considerable to spare for Cleveland.

The oils obtained from the shallow sands of Macksburg and Cow Run (140 to 600 feet), are of a dark-green color, have a specific gravity ranging from 42° to 46° B., and yield a large percentage of good illuminating oil; the percentage of amorphous paraffine is small, and their distillation yields a comparatively large amount of high test oil of light gravity. In these respects they differ from the deep oil of Macksburg in much the same way that the oil from Butler county differs from that of Bradford.

DISTILLATION OF PETROLEUM.

The products of the distillation of petroleum cover a wide range, and may be divided into three groups: 1st, those which evaporate rapidly; 2d, those which remain liquid; and 3d, those that are solid at ordinary temperatures. The first group contains the gasolines and benzines, or napthas. In the second are, standard carbon-oils from 110° to 150°, fire-test; water-white carbon-oils from 150° to 175°, fire-test; mineral sperm burning oil of 300°, fire-test; common, filtered and bloomless neutral oils, from 34° to 37° gravity; common, filtered and cold-pressed paraffine oils, from 25° to 30° gravity; common and filtered cylinder-stocks, black reduced lubricating oils, from 28° to 30° gravity, and residuum. The third contains the crude and filtered vasilines, crude and bleached paraffine-wax and coke points for the electric light.

In describing the process of refining, only those methods which are in common use will be given. Many of the products above-named are only manufactured by a few firms who have made a study of the chemistry of the subject; they are generally neglected by the average refiner, who does not employ an expert chemist, or have a laboratory for experimental research as a part of his plant.

The stills now in use are chiefly of a cylindrical form, containing from 200 to 1,000 barrels each; they are firmly set on a heavy brick wall in such manner as to expose the largest possible surface of the bottom to the heat of the furnace. The main point in setting is to have the entire bottom as evenly heated as possible. The outlet for the vapor into the worm of the condenser should be duly proportioned to the size of the still, large enough to allow the vapors to escape as rapidly as they are formed.

The crude oil is pumped into the still, taking the precaution to have it as free from water as possible; sufficient room must be left at the top for expansion and ebullition of the oil. While the still is filling,

a fire is started in the furnace underneath, and the firing is kept up steadily until the run is completed. The vapor passes over into the worm of the condenser, a large tank kept full of cold water, and is condensed. At the end of the condenser is the running box, where the specific gravity of the distillate is tested, and where it is turned into the receiving tanks. It is here that the separation of the distillate into the different grades of benzine, standard, water-white, etc., is made by shifting the steam at the running-box into the lines which lead to the respective tanks, when the desired degree of gravity is reached.

From the receiving tanks the carbon oil distillates are pumped into the "agitator," a large iron tank with a cone-shaped bottom, into which a strong blast of oil is carried from a double-acting air-pump or "blower." The distillate is first freed from any water which may be held in suspension; it is then "treated" with about two per cent. by weight, of sulphuric acid. The treatment consists in thoroughly mixing the acid with the oil by means of the air-blast, which is delivered upward from the bottom of the agitator. This removes any particles of fixed carbon or other solid matters, and also removes, to a great extent, the yellow color and disagreeable odor of the distillate. The agitation is continued until a sample taken in a test-glass shows that the "sludge" formed by the acid will settle quickly to the bottom of the glass, leaving the oil clear at the top. The blower is then stopped and the "sludge" allowed to settle in the cone shaped bottom of the agitator, from which it is then run into a spent-acid tank. It is better to draw out a little of the oil than to leave any of the acid in. The oil is then thoroughly washed with a large quantity of water until the water drawn off below shows no acid reaction. It is then treated with either a solution of caustic-soda or with aqua-ammonia, to remove any remaining trace of acid, and render the oil clear and bright. No excess of alkali should be allowed to remain in the oil. If the "treatment" has been properly conducted, the oil is ready for shipment when it leaves the agitator, although it is usually allowed to stand a short time in what used to be called the "bleacher," before it is shipped.

In the early days of refining, the whole run from the still was made into one grade of burning oil. It was soon discovered that this contained a dangerous element, which rendered it unsafe for family use. Inspection laws were therefore passed requiring the oil to stand a prescribed fire test. The United States standard test was fixed at 110° Fahr., for the burning point, and a heavy tax, at one time as high as twenty cents per gallon, was placed upon it. After the removal of the tax, 110° test was considered the standard until the several states began to pass inspection laws requiring different tests. Finally, public opinion in most

of the states has fixed upon 150° Fahr. for the burning point, as practically safe. The standard for export, however, still remains at from 110° to 115° Fahr. In order to make the oil stand the government test (110°), it was necessary to "cut off" the first part of the run and turn it into a separate tank. In some cases this product was allowed to run to waste, there being no commercial demand for it, and its exceedingly volatile character making it both difficult and dangerous to keep it in store. Its value as fuel was soon discovered, and many refiners burned it under the stills. The readiness with which it could be converted into vapor, and the value of this vapor for heating and illuminating purposes, soon led to the invention of the vapor cooking-stove, the gasoline street-lamp, and the gas-machine for private houses and factories. Having reached this point, it soon found its way into the retorts of the large gas companies as a substitute for coal. These several uses give the benzine or naptha series a commercial value equal, if not superior, to any other part of the "run" from the still. It is now carefully separated into different gravities, those destined for use in the gas-machine running from 85° to 90° B.; the grades intended for domestic use are deodorized, and have only one objectionable quality left, that is their inflammability.

By carefully excluding the benzine series at the first end of the run, and the crystallized paraffine at the other end, a distillate may be obtained which will, when properly treated, give a burning oil of 48° B., having an agreeable odor, white as pure spring-water, and which, at any temperature below 150° Fahr., will quench a burning taper. This is the "ne plus ultra" of the refiner, so far as a lamp-oil for family use is concerned, for it is not probable that a safer, better, cheaper or more agreeable home-light will ever be made from petroleum.

The refiners of Marietta and Parkersburg have never manufactured any products from that part of the "run" which lies between the burning-oil and residuum. The practice has usually been to cut the water-white distillate from the center of the run for 150° test, then to combine the two ends for 110° test; any distillate too heavy to go into the 110° oil is run back into the crude tank, and comes back into the still to be run over again. What remains in the still is drawn out and sold as residuum at about crude-oil price. Another plan is to stop the distillation when the oil in the still weighs from 27° to 30° B., allow it to cool and draw out and sell as reduced lubricating oil.

The neutral and paraffine oils have been neglected. Mr. George Rice, has, however, lately added to his plant in Marietta a filtering-house, and expects in future to give some attention to that class of products.

After the "run" is completed the residuum is drawn out, the still cooled down and the manhead is taken off; as soon as the temperature is endurable the men go into the still, scrape the coke from the bottom and clean it as thoroughly as possible; it is then refilled and started on another run. The average time made is about two runs each week; therefore, to find the weekly capacity of a refinery, its total still capacity is multiplied by two. This would make the present total capacity of the refineries at Marietta about 4,000 barrels crude per week.

The remainder of the work about a refinery consists in trimming, glueing and painting the barrels, filling and shipping the product. The crude oil, distillates and refined oils, are moved from one point to another, by the steam-pump, and, from large works, much of the oil is shipped in bulk by tank cars. Oil for the southern markets is filled into tin cans of five gallons each, two of which are packed in a wooden case; this is known to the trade as "case oil."

Marietta is favorably situated as a refining point for southern and western trade, and would probably refine a much larger portion of the crude oil produced in her immediate vicinity were it not for the powerful influence of the "Standard Oil Company," which carries the oil from her very doors to Parkersburg and Cleveland.

CHAPTER VII.

THE DRILLING AND CARE OF OIL WELLS.

By Fred. H. Newell, E. M.

An oil-well, as the term is used in the eastern United States and Canada, is a small circular hole of comparatively great depth, drilled through the surface soils and into the underlying rock, for the purpose of obtaining crude petroleum. The diameter of the hole, when finished, averages less than six inches, and the depth ranges from a few hundred feet to three thousand. As a rule, there comes from an oil-well, besides the petroleum, inflammable gas and water, more or less saturated with salt. The earliest of these small deep wells were drilled for brine for salt manufacture, then later similar wells were drilled for oil, and now many are drilled for the gas, as in turn it has been utilized.

A description of the ordinary methods of drilling oil wells, which by far outnumber salt and gas-wells, is equally applicable to all three classes, and it may be said that the chief difference between salt, oil and gas wells pertains to the relative values of these products, so often occurring together.

This inflammable gas is often greatly compressed, and when the well penetrates to the rock in which it is stored, the gas rushes out with such violence as to throw out at intervals not only oil, if present, but even the heavy salt-water. From these points of resemblance to artesian wells, that is, the small diameter and great depth of hole, and the pouring out of fluid, these wells have been incorrectly described as artesian wells, but in the one case the flow of water is continuous and quiet, due to steady hydrostatic pressure, and in the other the flow is intermittent and violent, due to an expansion of gas originally under a pressure, sometimes greater than the hydrostatic pressure of that depth. Flowing wells, especially when little or no oil is present, have been termed "geysers," but differ from the true geyser in that the salt-water is thrown out, not by expansion of a part of the water into steam by heat, but by pressure of a compressed gas existing in the earth at normal temperatures.

Until within the last quarter of a century, the drilling of deep holes has been in all countries, excepting, perhaps, in China, an experiment, when money and time were lavishly expended on each well in devising tools and acquiring skill in handling them. Since the time of the first drilling for oil in 1859, these operations have grown to a great industry, with men skilled in each of its numerous subdivisions, and large establishments especially devoted to the manufacture of its peculiar tools. The single fact that nearly one hundred million dollars has been expended since 1860 in making these "holes in the ground," will testify to the importance of this branch of mining. The head-quarters of this business, from which are sent out machinery and trained men to all parts of the world to drill for oil and gas, for water, both salt and fresh, and for other minerals, are the oil regions of western Pennsylvania, which may be considered as overlapping into New York and Ohio.

Although the tools and ways of using them are by no means perfect, and each year sees some improvement, yet there are certain definite methods and shapes of tools which are in general use throughout the entire oil-regions, and which are accepted as the present standard of excellence. These have resulted from the trial and frequent failure of the innumerable inventions of ingenious oil-men. The requirements to which all these inventions have had to conform, besides that of fitness for their purposes, are that they shall possess strength and simplicity of parts, since the operations are carried on often in the least settled parts of the country, and the tools are subject to all the rough usage of frontier work. A description of the drilling of wells in the newly developed oil-fields of eastern Ohio, can then be but a review of the latest, and, therefore, best practice in deep-drilling throughout the oil-regions. The most complete account of this, together with a description of machinery and tools is given in the excellent report of John F. Carll, of the Pennsylvania Second Geological Survey, published in 1880 (see Vol. III, page 285, etc). His descriptions have been largely used in the exhaustive report on petroleum, by S. F. Peckham, from the U. S. Census Office. (Report on the Production, Technology and Uses of Petroleum and its Products, by S. F. Peckham, Washington, 1885.)

Either of these works, supplemented by the finely illustrated catalogue of the Oil Well Supply Company (Bradford and Oil City, Pa.), issued in 1884, must give to any intelligent reader a clear conception of the ordinary processes. There have been few changes in the tools and ways of using them since Mr. Carll's report, and these have been mostly toward increase of strength and weight, and saving of labor.

The Process of Drilling.

The general principle of drilling is this: A long heavy bar, with its lower end dressed to a cutting-edge, is dropped into a hole in the rock, and by its weight cuts or breaks the stone where it strikes. At each blow it is turned a little, making a round hole whose diameter is just the width of the cutting edge. It differs from hand-drilling in a quarry, in that the drilling-bar is not struck by any kind of hammer. The drill is hung from the end of a rope by which it is lifted for each stroke. The process is then one of drilling simply, and not of boring, as it is sometimes called. After the drill has been working for a while, the chips of rock or drillings begin to fill the hole and break the blow upon the solid rock. To remove these the drill is taken out, water is poured in if the hole is dry, and the fluid mud thus formed is lifted out by a long narrow bailer with valve at lower end. These operations are alternated, first, drilling ahead about five feet, then cleaning out the fine mud, drilling again, and so on, day and night, till the desired depth has been reached. The drill is not actually one solid bar, but is made in several pieces, together called a "set of tools." The lower end, or bit, when dull, can be taken off and another put on while the first is being dressed. Experience has shown that five and one-half inches is the most suitable diameter for oil-wells. In general, the smaller the hole the less the expense, because the machinery and tools can be lighter and more quickly handled, but for much less than five-and-a-half-inch the tools cannot be made large enough to give the necessary strength and weight for deep-drilling. For a larger hole than this the progress is slower, unless there is considerable outlay in making all the parts heavier and stronger. The large gas-wells about Pittsburgh are drilled six inches in diameter.

Requisites for Drilling.

To drill a well, either for oil, gas or water, the principal necessities are a carpenter's rig, boiler and engine, set of drilling-tools, including rope, and usually casing to shut off surface-water. It is customary for the owner to provide the rig, boiler, engine, casing, tubing and water-supply, and to let the drilling of the well at so much a foot to a contractor, who furnishes his own tools and fuel, and does all the work of putting down the well, leaving it in shape to flow or be pumped. The contract price depends largely upon the difficulties peculiar to each district.

In Ohio, in 1885 and 1886, the rate in the Macksburg field was 75 to 80 cents per foot, while in Bradford, Pa., it was 45 to 50 cents, and for the deep gas-wells of Washington county, Pa., from $1.50 to $2.00.

The Rig.

The term rig includes all the woodwork and its necessary iron fittings, put together so that when boiler and engine are in place, drilling can begin at once. The rig consists of derrick to carry a sheave called the crown pulley, at sufficient height to swing the drilling-tools free from the ground, bull-wheels and shaft on which the drilling-cable is wound sand-reel at one side for winding up the smaller rope used in cleaning out the drillings, walking-beam to give vertical motion to the tools, band-wheel for transmitting power from engine to these moving parts, and foundation timbers and posts which support them all. Besides these, are foundations and house for engine and protection for rubber belt connecting engine to band-wheel.

The most conspicuous object in the country is the derrick, towering above the houses in the towns, standing in the open fields, rising among the tree-tops in the woods, or crowning the summits of the hills. On page-plate I, is shown a side elevation of the derrick, with belt and engine-houses. This represents the style in use in the Macksburg field. It is what is commonly known as a winter-rig, the lower part of the derrick being boarded in and a roof built to protect the men from the sun and rain and from the shower of salt-water from the ropes, when they are drawn out of the wet holes. Page-plate II gives the rig again with the roof, engine and belt houses taken off, showing all the machinery in place and the tools just entering the hole. In this plate the engine is put closer to the band-wheel than in the previous one, in order to show the boiler on the extreme left.

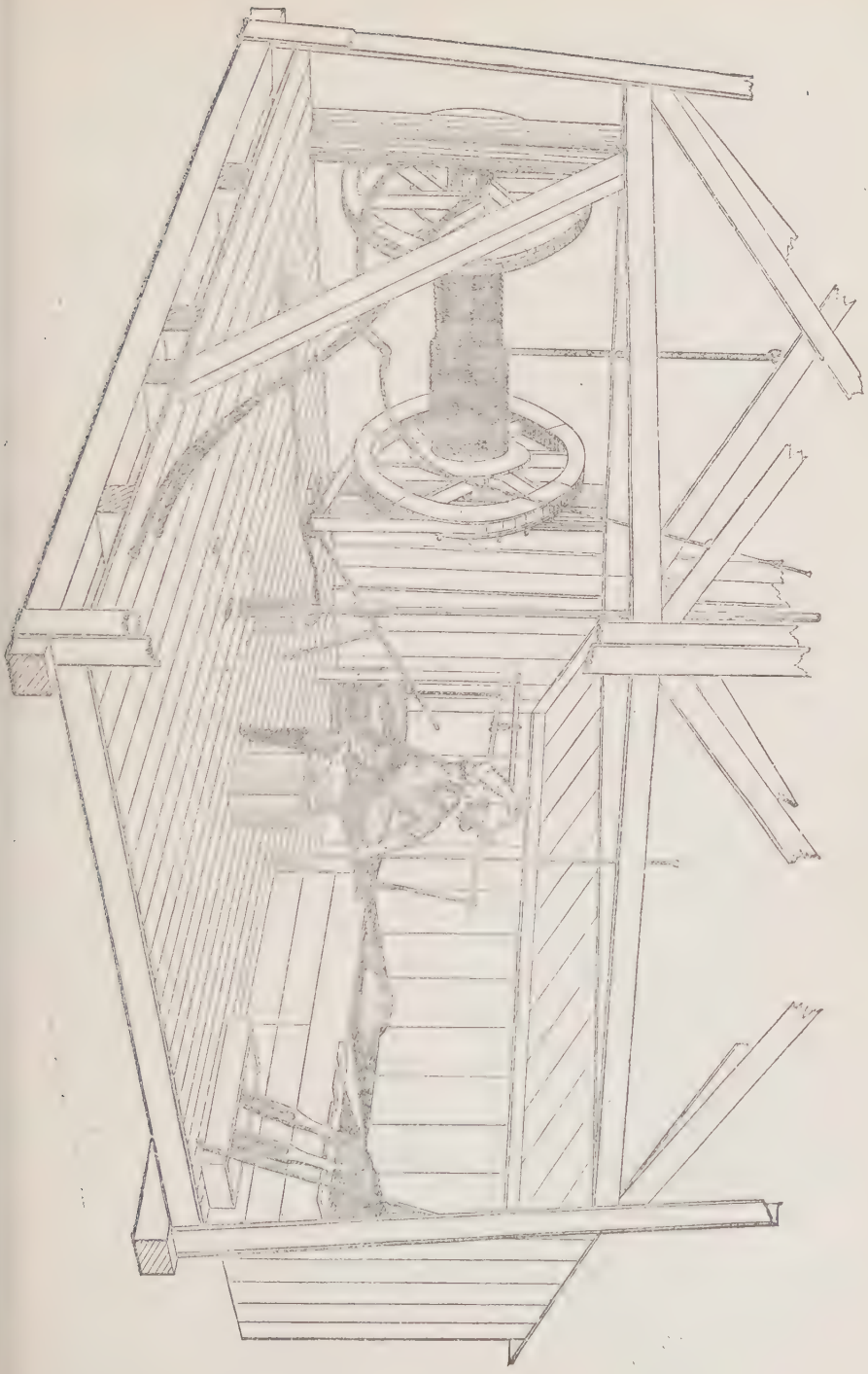
All parts of the rig rest upon timbers which are sawed out, or, in the woods, merely flattened on two sides, no masonry being used about the well. These are particularly shown in the drawings; for full details of size and shapes, reference must be made to the Census Report, or to the catalogue of the Oil-Well Supply Co. The lowest set of timbers, those lying transverse to the length of the rig, lettered *K* in plate II, are called the mud-sills, being partly bedded in the soil. The main sill *O*, and the sub sills (not shown, being on the further side of the main sill and nearly parallel to it), lie across these, and are firmly fastened to them by gains and keys. The main and sub sills support the principal part of the machinery of the rig.

The derrick stands on six posts, lettered *J*, one at each corner and one in the center of the sides. On them rest two sills and across the sills are six floor-sills, *H*. The two center ones are placed quite close together, leaving only room for the casing or conductor-box of the well. They are higher than the ones on either side, so that the floor planks

will slope away from the hole and can then be kept cleaner and drier. The derrick is twenty feet square at base; the other sides are similar to the one shown in elevation. It is built of two-inch plank spiked together; the cross-braces *D* are inch-boards. The corner pieces *E* are sixteen feet long, excepting the lowest one. They are nailed together at the edges, breaking joints at each girth *B*, thus making the girths eight feet from center to center; the lowest girth is nine feet from the floor. On the further side of the derrick, as shown in the plates, a ladder is usually built; when there is none, the men must climb by the girths and braces, if necessary, to go to the top. The drawings show a nine-girth derrick, which has been the customary height, but in Macksburg, where tools of extra length are used, ten or eleven-girth derricks are not uncommon. On the extreme top, supported by a strong frame-work, is the crown-pulley *x*, resting in its block, *F*. At the right hand side of the lowest part of the derrick are the bull-wheels *M*, with the rope wound on the shaft; another view, showing the wheels in perspective, is given in the background of plate V. This is the windlass on which the drilling-cable is wound. On each end of the twelve-inch hard wood shaft is a wheel, seven-and-a-half feet diameter. The wheel on the left of plate V, has a groove to receive the tug-pulley. This is a plain laid rope *f*, on plate II, connecting the bull-wheel with the tug-pulley. It is always crossed as shown in the drawing, to give it a better hold on the wheels. The wheel on the right hand end of the shaft is encircled by a brake-band, shown with its lever, *h*, on plate II, and also in larger scale on plate V. On the left of the derrick is the walking beam, *U*. This is twenty-six feet long, twelve inches wide, and twenty-five inches deep at center, and is cut away on the lower side, so that it is twelve inches square at the ends. It is supported at the middle, oscillating up and down on the center irons, *k*.

These are bolted to the top of the samson-post *P*, which stands on the main sill *O*, and is propped on each of its four sides by the braces *p*. Under the end of the walking-beam is the band-wheel *S*, keyed to the shaft *s*, which rests in grooves cut in the top of the jack-posts, of which the front one only, *Q*, is shown. This wheel is connected at all times to the pulley of the engine by an eight-inch rubber belt. It is nine feet in diameter, and has on the side not shown a groove wheel called the tug-pulley.

The band-wheel can transmit motion in any one of three ways. 1st. When the pitman of the walking-beam is put on the crank of the band-wheel shaft, as shown in plate I, the beam is made to move up and down. 2d. When the pitman is off, the beam tipped as in plate II, and the bull rope *f* put on, connecting the tug pulley and the bull-wheels as



there shown, the bull-wheel shaft is made to revolve, winding or letting out the cable. 3d. When the bull-rope is thrown off, and the friction-pulley of the sand-reel *T* is drawn against the band-wheel by levers *N* and *r*, the sand pump line B, is wound on its shaft.

All the upright posts and braces which support the moving parts, and also the sills, are gained and keyed together, no mortices and pins being used. This gives great solidity, and any part can be tightened or lined-up by driving in the keys, or quickly taken out. Plates I and II represent the jack-post *Q* in plate II, as standing on the main sill. A later plan is to use a longer post and gain it into the further side of the main sill, and also into the side of the mud-sill *K*. By so doing, the main sill is not thrown so far out of square with the rest of the timbers as when the samson-post and jack-post are both put on top.

Cost of Rig.

A rig requires about ten thousand feet of sawed lumber. Hemlock is generally used, but in Macksburg this wood cannot be had, and poplar and oak, costing $15 per thousand are commonly employed. The hewed timbers cost $25 to $30. The band-wheel and bull-wheels are preferably bought ready-made, but in Ohio it is usually found cheaper to make them on the spot to save cost of transportation. A complete set of rig-irons, that is, the shaft and fittings for band-wheel, all the pulleys, gudgeons, bolts, etc., used about the rig, costs $65. The aggregate time required to put up a rig is from twenty five to thirty days; that is, three men working eight to ten days each; usually, three men are employed, the boss rig-builder, who generally takes the work by contract, and two helpers. Wages are, for the boss when working by the day, $3 to $3.50; for the common carpenters, $2 25 to $2.75.

These items may be put as follows:

Sawed lumber, 10,000 feet, at $15	$150 00
Rig timbers	30 00
Rig irons	65 00
10 days' labor at $3.50	35 00
20 days' labor at $2.50	50 00
Teaming, grading, nails, etc	45 00
Total	$375 00

The total cost ranges from $350 to $400. To save expense, when the wells flow quite steadily, many of the producers in the Macksburg field, when one well is drilled and tubed, take down the rig and use it for the next well. The cost of taking down and putting up the rig again is

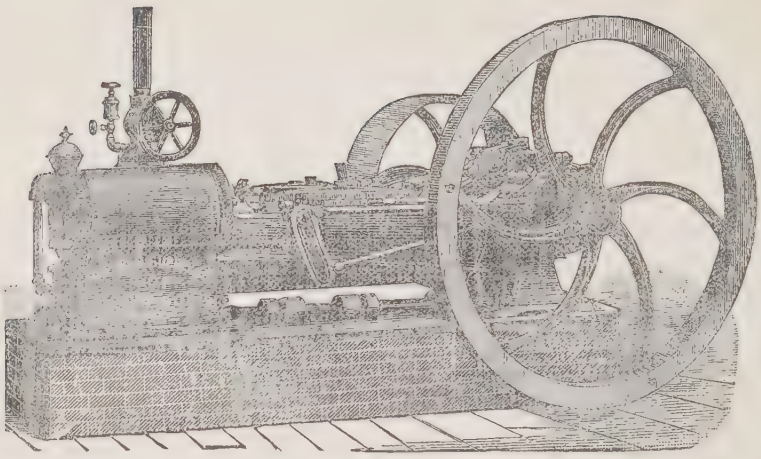
about $75, to which must be added $25 for new lumber to replace that broken in cutting down. This is a considerable saving of outlay for rig-irons and timber to a person operating with small capital, but if the wells stop flowing and need cleaning out, the rig must be, in part at least, put back.

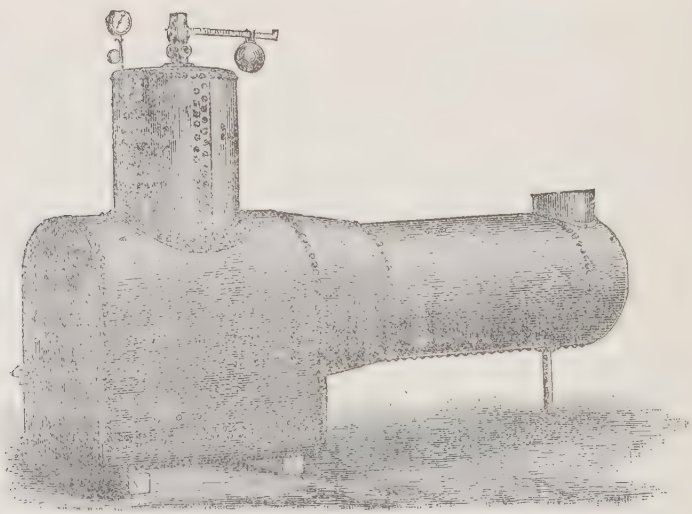
Boilers and Engines.

The boilers and engines for drilling and pumping wells are made especially for that purpose, and though manufactured by various firms holding patents on specialties, yet are similar in general design. Those used in Ohio are, almost without exception, made by Pennsylvania companies at Oil City, Warren or Titusville. The cuts on plate III represent a kind as widely used as any. The life of the boilers and engines depends of course largely upon the care shown in their usage; they should put down eight to twelve wells, and then be suitable for pumping or doing such light work.

The boilers are tubular, built in style of locomotive boiler. They are set up at a safe distance, on any convenient spot, away from the engine, say thirty feet, in a direction opposite to that of the derrick, to avoid danger of igniting the gas from the well. They are usually twenty-horse power, have thirty six to forty tubes about three-inch diameter, cost $450. A few fifteen-horse power boilers are in use, but they require careful attention in order to furnish enough steam. The fire-box, in addition to usual firing-door, is provided with hole through the front to admit gas-pipe. The fuel preferably used is gas. In the Macksburg field, gas is used wherever it can be obtained without great expense for piping. It is commonly burned as it flows from a perforated pipe, little effort being made toward economy by use of atmospheric burners or similar contrivances, since the price is so much per day regardless of the amount used. Gas costs for a drilling well about $3 a day, or by contract $100, for enough to put down the well. Most boilers, however, are fired by the Macksburg coal, which crops out on the hillside and is mined from numerous openings. The cost is six to seven cents per bushel, delivered; total cost of coal for drilling, say thirty-five days, is $90 to $180. The steam-pressure is 90 to 100 pounds per square inch, often carried to 120 pounds. For pumping the old shallow wells scattered along Duck Creek, there are still in use a number of the old fashioned cylindrical two-flue boilers, set in masonry, but these are not used in the new development.

Economy of steam being of secondary consideration, the engines are built with more regard to strength, simplicity, quickness in starting





and reversing, easy replacement of parts, and compactness, so that they may be safely moved from place to place. They are ordinarily fifteen-horse power, though many twelve-horse power are to be found in use. The cylinder is usually eight or nine-inch diameter, stroke twelve to thirteen inches. The engine is bolted to a heavy stick of timber, *m*, on plate II, which, in turn, is keyed into short timbers, gained into mud-sills. The cut of the engine on plate III, shows the engine-block painted fancifully to represent brick-work; no bricks are used, however, about the rig. The engine is placed about thirty-five feet from the band-wheel to which it is belted. A stout brace, *l*, holds the engine-block from being

pulled forward by the belt. Steam is carried from boiler to engine by a a two-inch pipe, not often protected by any covering. The engine can be controlled from the derrick by means of cords. The throttle-valve is provided with an upright grooved wheel, around which passes a small endless rope called the telegraph cord. This is continued out into the derrick, where it is wound once around a similar wheel, which is so mounted on a bearing that the rope can always be kept taut. By turning this wheel in the derrick, the throttle-wheel connected with it, is turned in the same direction. Plate II shows the whole arrangement, the cord being represented by the two parallel lines lettered b^1, the wheel in the derrick, b^2.

Another cord is fastened to the top of the reversing link of the engine. This runs up over a pulley and out into the derrick, its knotted end hanging beside the telegraph pulley. By these two cords the driller, without leaving his post, can stop, start, reverse or change the speed of his engine. The reverse link is shown in plate III, on the side of the engine-bed. The cord is fastened into a little eye (not clearly seen) on its top. The link is not only necessary in reversing to run backwards continuously, but is also of great service in starting the engine when it has a heavy load to move. For instance, when starting to pull the tools out of a deep hole, the engine often gets stuck on the dead center. Then the driller, standing with one hand on the telegraph cord and holding the reverse cord in the other, skillfully alternates the motion, until the fly-wheel acquires impetus to swing the crank over the center.

Water Supply.

After the well-owner has provided for rig, boiler and engine, the next thing is the supply of water. If he is so fortunate as to have an inexhaustible spring or brook of soft water near by, his only expense will be for inch-pipe. In Ohio, however, good water is not to be had so easily, and especially in summer, and for wells on the hills it is forced long distances. In this case, a tank must be set up near the rig to hold the water when it comes. It is customary to set the ordinary 250 barrel tank, which can be used to hold oil when the well is done. Plate II shows this tank, *I*, out beyond the engine. While drilling in a dry hole the tank must, generally, be filled twice a week. The water is used for steam, to wash the derrick floor, and also is thrown into the hole to make a fluid mud of the drillings, so that they can be bailed out. When, however, the hole is kept full of water from some wet strata, no water is thrown in, and a tank full will last a week. When water is forced up to a number of drilling-wells, the cost is from $75 to $100 each. From

the tank, or other source, the water is forced into the boiler through an inch-pipe by a plunger-pump on the engine. When the steam and water connections have been made between boiler and engine, all is ready for the contractor to hang his tools.

Drilling Tools.

A full set of drilling tools consists of—

	Cost.
1 temper-screw	$50 00
1 rope-socket, weighing 75 pounds	16 00
1 sinker-bar, 16 feet long, weighing 600 pounds	48 00
1 set jars, weighing 300 pounds	105 00
1 auger-stem, 3⅜-in. diam., 40 feet long, weighing 1,300 pounds	85 00
2 bits for 5⅜-in. hole, weighing 150 pounds each	70 00
2 bits for 8-in. hole	90 00
2 tool-gauges	2 00
2 tool wrenches	24 00
1 wrench-circle	5 50
1 wrench-bar	4 50
Total	$500 00

Besides these, a contractor needs—

1 cable, 1⅞-in., say 1,600 feet long, weighing 2,000 pounds, @ 14c	$280 00
1 sand-line, ⅞-in., say 1,600 feet long, weighing 450 pounds, @ 14c	61 00
Set blacksmith's tools, anvil, bellows. forge, sledges, etc	40 00
Bailer, 30 feet long, @ 85c. per foot	25 00
Sand-pump	25 00
Incidentals	19 00
Total	$950 00

The above are list prices on which there is a discount for cash, so that a good outfit is estimated to be worth at Macksburg, $850.

In addition to these necessary tools, the contractor, especially if at a distance from a large machine shop, finds it economy to own a few of the commoner "fishing" tools, such as extra rope-socket, sinker-bar, jars, horn-socket, slip-socket, rope-spears and grabs, costing, say, $350.

On the left-hand side of plate IV are shown cuts of the principal pieces which make the string of tools. The bit, figures 6 and 7, is the lowest. This has the edge which does the cutting, and is dressed out as it wears away. The shape of the bit is not like a cold-chisel, tapering toward its point, but below the neck it is made of the same size down to where it is dressed. Here it is spread to full five and one-half inches, and is hammered so that each corner forms the arc of a circle of that diameter. That it shall be exactly the same size each time, and dressed to a true circle, a tool gauge, figure 9, is used. The point is hammered

until the gauge just fits over it; for a five and one-half inch bit this is made five and five-eighths-inch diameter to allow for the expansion of the hot iron.

The bit is screwed into the lower end of the auger-stem, figure 4. This is to give weight, that the bit shall strike a powerful blow. It is generally thirty-two feet long, but in Macksburg heavier, and therefore longer ones are used. A stem there is made long to offset the loss of weight of the tools in the salt-water, at the same time keeping it as small diameter as possible that it may fall rapidly, the principle being that, if the weight were increased by using larger diameter, the space between the stem and sides of hole would be diminished, and the water displaced by the movement of tools could not flow around them quickly. Stems, thirty-eight and forty feet, are common, and some are even fifty-two feet long, the latter being made in two pieces. *Note.*—(After the stems have been in use for a time they become powerful magnets, and will attract and support small pieces of iron; one-half dozen twenty-penny spikes may be hung, one below the other, from the steel boxes.)

Above the stem are the jars, figure 5. They are formed of two pieces of steel, slotted and interlocking in such a way as to a low a longitudinal movement or play of about nine inches. They thus divide the string of tools into two parts—the lower, or cutting portion, consisting of bit, auger-stem and lower half of jars; the upper, or jarring portion, made up of top half of jars, sinker-bar and rope-socket. When the tools are hung up, the jars are open, as shown in the cut, and when they reach bottom, the jars close together, shortening the tools by the nine-inch play. As the name implies, their use is for jarring, that is, to give a sharp upward blow to the cutting portion of the tools whenever the bit becomes stuck fast. The bit, while in use, gradually becomes worn on the sides, that is, looses its gauge. When it has drilled a "screw" about five feet, it is pulled out, and a new bit dressed out to full gauge, 5½-inch (in small hole) is put on. When this new bit is lowered into the hole, cut by the worn bit, it often sticks at first, and were it not for the jars to give it a quick lifting blow, it could not be pulled loose without danger of breaking the cable. The theory of the use of the jars in drilling has been slightly modified since the description given by Mr. Carll, on page 2 9 of III Pennsylvania, Second Geological Survey, and copied on page 81 of Peckham's Report.

The tools are lowered into the hole until they touch bottom, then are lifted a few inches or a foot or more, depending upon the length of rope in the hole, then the rope being attached to the walking-beam by means of the clamps below the temper-screw, and put in motion, the tools are raised and lowered. The impetus of the tools is so great and

the rope so elastic that, although when at rest the bit hangs away from bottom, yet, when in motion, it strikes the rock with great force, and quickly rebounding stirs up the sand formed by cutting. The jars should not open and leave the lower part of the tools resting for an instant on bottom, as was the old method, but are kept drawn out all the time. This is called drilling by the spring of the rope or "bouncing the drill." It is in almost universal use, being quicker then the old method. It has the disadvantage that the rope, jars and machinery are subject greater to strains and are worn out more quickly than by the other way.

A good driller never allows the jar to strike together on a downward blow as, not being made for such use, they wear rapidly and break, or "boot-jack," as is the driller's term.

Drilling without jars has been and is occasionally done to a very limited extent. The jars are left out of the string of tools, and the sinker-bar, the piece next above is screwed into the auger-stem. This gives greater weight, and consequently, speed to the drill without increasing the total weight of the tools. The drilling in this case is necessarily done by the spring of the rope. It is attended with great risk, for, if the stone should fall or mud run in, wedging the tools, they could not be jarred loose. Then the cable must be cut close above the tools, fishing tools procured, and the stuck tools fished out, as described further on.

Above the jars is the sinker bar, figure 3; this is of the same diameter as the auger-stem, but shorter and lighter. Its purpose is to give efficiency to the upward blow when jarring.

The rope-socket, figure 1, is the top piece of the string of tools, and in this the end of the cable is fastened. In the kind represented, the rope is held by rivets, but there are other patent sockets where the end of the rope is held by being wedged in a tapering-hole.

These tools are all screwed together, the upper end of each piece excepting, of course, the rope-socket, having a pin with thread cut on it, and the lower end of each, excepting the bit, a box with hole having threads of same size. The tools shown have the old-fashioned cylindrical pins; lately, however, the taper joint shown in the upper right-hand corner of the plate, figure 14, has come into general use. Some of the advantages of the taper joint are, that the area of the base of the pin where a break usually occurred is made more than twice as great, also thickness is added in the same manner to the box in its weakest place, and also the bit can be screwed on or taken off in two or three turns.

The joints are tightened or "set up" when the string of tools is partly in the hole, by means of the wrenches, fig. 8, plate IV, which fit

around the square neck of each piece. The head of the wrench is larger than the hole in the derrick floor; as the string of tools is descending, the wrench is pulled around the neck of one piece, for instance, the sinker-bar, below the pin, just as it is going through the floor. The bar then hangs suspended from the wrench, which, in turn, rests on its broad head on the floor across the hole. The other wrench is then put around the neck of the rope-socket above the box. The lower wrench is held from sliding about by a pin in the floor, which presses against the little crook in the end of the handle. By means of a crowbar placed against the end of the upper wrench, two men, using all their strength on this compound lever, screw up the joint. Each joint is, in turn, "set up" in this way, since the constant jarring and twisting of the tools when at work has a powerful tendency toward unscrewing them.

Plate II gives on a small scale the string of tools all put together and hung in the derrick ready to be lowered into the hole by the cable, which runs up over the crown-pulley and down around the bull-wheel shaft. The cable is a hawser laid rope, 1⅞-in. diameter. Its length when new depends upon the depth of the hole to be drilled; a new 1,600 foot cable will drill a 1,600 foot hole, the rope stretching more than enough to reach from bottom of hole to top, and then up over derrick and down to shaft. The stretch is generally calculated at ten per cent. A cable will often drill three wells, or say 4,500 feet, but in Macksburg, owing to the destructive action of the salt-water, it is seldom considered safe to use a cable more than twice; the unused end can, however, be employed where a short line is needed.

Temper Screw.

The cable is suspended from the end of the walking beam when drilling, by means of the temper-screw shown on plate IV, fig. 2. It is a contrivance for letting out the cable slowly as the drill cuts into the rocks below. It is hung from the drilling-hook of the beam by the eye in its top. On the lower end are clamps held together by a set-screw firmly gripping the rope, which has previously been wound with soft hemp to prevent any injury. Above the rope clamp is a swivel, so that the rope can be twisted without turning the screw. The nut in which the screw travels is made in two pieces, each half fastened to the lower end of one of the long bars, called the "reins," on each side. The two parts are encircled by a small set-screw fastened to one of them. When this set-screw is tightened up, the nut binds in the temper-screw so tightly that the latter will not turn; on loosening the set-screw the temper-screw can be turned, lowering the rope; when, finally, the tem-

per-screw has run down as far as it can go, and the rope has been taken out, the set-screw is turned back far enough to let the nut fly open and the temper-screw is pushed up to the top again. This saves time and labor in running up the screw, which is five-and-a-half feet long. As the screw and its clamps are heavy for one man to push up, they are counterbalanced; two cords being fastened into the little swivel on top of the screw, then running up over pulleys on the walking-beam and out to weights near the samson-post.

The Men and Wages.

On a drilling-well there are employed four men—two drillers and two tool-dressers; one driller and one tool-dresser working from noon till midnight, or the afternoon tour (pronounced tower), the other driller and tool-dresser from midnight to noon, or the morning tour. The drillers must be men of long experience, for on their skill and judgment depends the success of the work. Their duty is to stay in the derrick to attend to the drilling proper, turning the cable, and keeping one hand on it or on some portion of the temper-screw at all times while the drill is at work, or controlling the machinery by cords and lever when changing the bit or sand-pumping. The tool-dresser is the helper to each driller. He fires the boiler, attends to its feed-water, oils the engine and machinery, and, as the name implies, dresses the bits as each in turn becomes worn. The wages of drillers in most places in Ohio are $3 to $3.50 a day; of tool-dressers, $2.50 to $3. Often the contractors, when having but one well, do the drilling themselves, or one driller may take a contract and hire the other men. The profits of contracting depend upon the success in putting down the well quickly and avoiding accidents; with ordinary good luck they may be, say, $200 to $400, and, on the other hand, the contractors may lose heavily. There are cases reported where contractors have lost two complete strings of tools in one hole, spent three to four months trying to recover them, and finally were compelled to abandon the undertaking, with loss of from $2,000 to $3,000.

Beginning to Drill—Spudding.

At first, to save the long cable from the rough handling of starting the hole, a short piece of old rope is used in its place. This is fastened into the rope-socket of the tools, carried up over the crown-pulley, brought down and wound around the bull-wheel shaft. As is obvious, the tools being sixty feet or more in length, cannot be suspended from the walking-beam until they have got below the surface of the ground, so in the beginning another way of lifting them out must be used. This

process is called spudding. The tools are lowered into the hole, cut in the planks of the floor exactly under the end of the walking beam, and when the drill just touches the soil the brake of the bull-wheels is thrown down holding the tools with jars open. One end of the jerk-line, a piece of cable with loop at each end, is put over the wrist-pin of the crank of band-wheel, the other end brought into the derrick and fastened tight by small rope, noose and wooden-pin to the cable, a few feet above where it leaves the bull-wheel shaft. The engine now being started, the crank revolving pulls on the jerk-line, draws the cable toward it, and as this cannot unwind from the shaft, the motion is transmitted up over the crown pulley, lifting the tools; the crank making a half-revolution, the tools fall. Thus, at each revolution of the crank, the jerk-line is given a violent pull and the tools are lifted by the spring of the rope. The driller meanwhile turns the tools and occasionally lets out a few inches more rope by lifting the brake of the bull-wheel. When he thinks that the bit is dull the tools are hauled out, the fresh bit put on, and the drillings in the hole cleaned out by the sand-pump.

The soil around the upper part of the hole, that is, from the ground to the firm rock, must be held from falling in. For wells on the hills where the distance is but a few feet, a shaft is dug by hand, and a conductor-box made of plank eight inches square inside is set on bed-rock. When the soil is too deep to dig in this way, a very large bit is used, and in the hole thus made octagonal wooden boxing, or iron casing, is inserted. In many places the soil is very deep and will not hold itself up while being drilled, and drive pipe must be used. This is extra-strong pipe, usually eight inches diameter, with steel shoe on lower end. It is driven by a heavy maul, a log of wood, lifted as the tools are when spudding, and running in temporary guides in the derrick. That the pipe may drive more easily, it is usual to drill inside, clean out the earth and cut ahead, loosening the hard clays or breaking any boulders in the way. The Macksburg field being south of the line of glacial drift, does not have such thick deposits of clay and gravel in the bottom lands as the Pennsylvania fields, so pipe is seldom driven. In the valleys, a spudding-bit twelve to fifteen inches across, is used to cut through the soil, and the octagonal wooden conductor-box, or large casing, 7⅝-inch internal diameter, is put in. Casing is preferable, as it shuts off the surface water better. When this is set, the 7½-inch bit is put on, and if not already done, the hole spudded down until the tools are buried below the derrick-floor. Then the rope can be attached to the walking-beam by the clamps of temper-screw, and the regular drilling begins.

Drilling.

The tools having been lowered into the hole to proper depth, and suspended from the clamps of the temper-screw, as told on page 488, when describing the jars, the brake of the bull-wheel is thrown up, letting slack the cable above the clamps. The tool-dresser then turns the bull-wheel backwards, and unwinds about thirty feet of the cable, and, catching hold above the clamps, pulls this down, so that it lies loosely coiled on the floor. In the meantime the driller has started the engine, and the walking-beam rocks up and down, at the rate of about twenty-five strokes a minute, lifting the tools with it. He then puts a stick through the rings below the temper screw, and begins to turn the rope. As he turns, the slack part of the cable loosely winds around the taut portion below the clamps, and so, after going in one direction for a while, he begins to twist in the opposite way, uncoiling the slack rope, and coiling it again in the other direction until the slack is again wound up, when he begins to turn as at first. The twisting of the rope turns the drill below, so that it cuts a round hole. The driller at all times has hold of the rope or a stick connected to it, and by the feel knows how the tools are working, whether the rocks are hard or soft and, if skillful, should be able to tell in an instant if any piece breaks or becomes unscrewed. Occasionally he stops turning, loosens the set-screw, and runs out the temper-screw a turn or two, letting the tools lower. When, at length, in perhaps two or three hours, the temper-screw has all run out, that is when the drill has advanced five feet, the tools must be taken out to clean out the drillings and, if necessary, to put on a sharp bit. To do this, the slack cable is pulled out on the floor again, and the bull-rope is put on, setting the shaft in motion and winding up the cable. At the exact instant the shaft of the bull-wheels take the weight of the tools from off the walking-beam, the machinery is stopped, and clamps of the temper-screw are taken off. Then the pitman is pulled from the wrist-pin, allowing the walking-beam to tip back, and the temper-screw is swung back and fastened out of the way. The engine is again started, and the tools are drawn out of the hole. As the top of the bit comes in sight, the engine is stopped, a wrench is pulled under the pin of the bit, another wrench put on the auger-stem, and, with the aid of a crowbar the joint is loosened. The tools are then hoisted clear of the floor, the bull-rope thrown off, and the tools caught from falling back by throwing down the bull-wheel brake. They are now swung to one side out of the way of the sand-pump, the tool-dresser takes off the bit and puts on the other. The driller pulls forward the lever by his side, bringing the friction-wheel of the sand-reel

against the band-wheel, winding up the sand-pump line and lifting the pump. This is swung over the hole, and the driller, lifting the lever, throws off the friction-wheel, and the pump falls by its own weight. When it has reached bottom and filled with mud and sand by the valve in its lower end, the driller throws the lever down, the reel winds up the rope bringing up the pump; this is tipped over and lowered again, the operation being repeated until the water, which it brings up, is comparatively clear. Then it is put aside, the tools are swung back over the hole, lowered a little, the joint of the bit "set up," and then they are allowed to fall into the hole, checked from too rapid descent by the brake on the bull-wheel. Again the rope is clamped to the temper-screw, which has been run up, and drilling goes on as before. The tool-dresser takes the worn bit and places its end in the forge to heat preparatory to dressing it. The bellows are blown by a rope, one end of which is connected to the handle and the other to the pitman of the walking-beam. Plate V, showing the interior of the derrick, gives the position of the forge, bellows, anvil, etc. After the bit is hot it is hammered out to shape by sledge, and dressed to gauge. With very soft rock the drill may not be worn enough to necessitate changing at each screw, and when the hole is full of water, and the drillings mix well, that is, are held in suspension, sometimes two or more screws may be run without sand pumping.

Wet and Dry Holes.

In most oil-fields salt-water is found only in the strata lying within a few hundred feet of the surface. In these places an eight-inch hole is drilled below the point where salt-water comes in, and casing, 5⅝-inch internal diameter, is set, shutting off all the water. When the casing has been set, bits, 5½ inch across, are used and the hole continued inside the casing through the dry rocks to the desired depth. In Macksburg, however, salt-water is generally found in all the sandstones down to the oil-bearing sand, and thus drilling there differs from other fields in being done in water for the larger part of the depth. The early wells were drilled dry, 4¼ inch casing being put in after passing through the salt-water sand, and the rest of the hole, only about 300 feet, was drilled with small tools. From experience in former fields, at that time it was thought that if the oil-sand was drilled into with the hole full of water, the well would be injured by water being forced into the sand. Some person, perhaps not being able to procure casing, drilled a wet hole, found it could be done, and since then very little of the small casing has been used.

The advantages of drilling dry, when it is possible, are, that drilling is done faster, the tools not being buoyed up by the salt-water, the rope lasts longer, small shows of gas and oil are more readily detected, and their position located. Also, if tools are lost in the hole, they can be more easily recovered, as the fishing tools are used to better advantage than when the hole is full of water.

On the other hand, the advantages of wet drilling are, that it is cheaper, there is no outlay for the small casing, no time is lost in putting in casing and in changing the tools for a smaller set, and when the well is down, the shot has much greater effect, being tamped by the column of heavy salt-water. The greatest disadvantage is that the sides of the hole are kept wet, tending to soften some of the shales into a semi-fluid mud which caves rapidly, and when there is delay by lost or stuck tools, there is always danger of sand and mud settling around the tools, even if a decided caving of the side does not occur. That the Macksburg wells can be drilled wet without injury to the oil-sand, is due to the great amount of gas which at present is able to keep the sand from being flooded by the salt-water. Whether this way of drilling can be done successfully when the gas weakens is a matter of doubt.

The drilling in that field being done so largely through the Coal Measures, there are met many bands of soft clays and fine shales of all colors, which disintegrate rapidly when exposed to air and water, forming mud. Those above what is known as the "300-foot" sand, are notably troublesome, especially if the surface water has not been shut out of the top of the hole by the large casing. To avoid trouble from this upper mud, the "big hole," 7½-inch, is drilled as rapidly as possible to the 300 foot sand, and the 5⅝ casing set in the top of this. When this casing has been put successfully in position, the larger casing at the top is drawn to use in another well. Below this point there is less danger of caving, but there are still many places from which mud and loose rock may fall; and if the tools are stuck for a few hours they are liable to be buried up and must be speared loose.

Rate of Drilling.

Wells in this field, 1,700 feet deep, have been put down in twenty-five to forty days, if not delayed by unusually "bad luck." The rate of drilling at the top of the hole is from 25 to 50 feet per tour (twelve hours); some men claim to have made 100 feet. In the small hole, 5½-inch, where the tools are retarded by salt-water, the progress is 12 to 18 feet a tour; the rate depending not only upon the hardness of the rock, but also on the fragments mixing well.

Caving.

The steady downward progress of the drill is liable at any time to be interrupted by accidents, such as by caving of sides, breaking the tools in the hole, or getting the bailer stuck and losing it by breaking of sand-line. The most frequent cause of delay and expense, one for which the Macksburg field is distinguished, is from caving. If the large casing or conductor-box keeps out surface-water, the drilling may be dry for a time, but water comes in before going far, and the driller hastens the 8 inch hole to get the 5⅝-inch casing set before the rocks of the upper part of the well have time to soften. After the casing has been set the 5¼ inch hole is continued dry, and if the shallow oil-sands do not contain water, which, however, they usually do, it may be kept in this condition till the salt-water sand is reached. In this case the drillers take the precaution to lower water needed for drilling into the hole by bailer instead of pouring it in and letting it flow down on the sides. On striking this sandstone, brine rises nearly to the top, so that from this time the casing is of use, not in keeping water out, but in holding the rocks in place.

After the 5⅝-inch casing has been set a soft place may be encountered below, which caves so badly that progress is impossible, the mud even rising in the casing. Usually the casing is drawn, the 8 inch hole reamed down, and the casing reset. There are wells where the casing has been set four or five times. This operation is of course very tedious and difficult, for when the casing is drawn, caving may take place from all the bad spots above. To obviate this danger there is now used a bit which will go inside the casing, and when below this, spring out and cut a large hole so that the casing can be driven down. This is said to be very successful in soft rocks, and if so, will prove of great service to this field.

Fishing.

The operation of recovering a tool, or removing any such obstruction in the hole, is known as a "fishing job."

The tools for this purpose are innumerable, varying with the peculiarities of the accident and the facilities at hand. Their construction brings into play all the ingenuity of the machinist, and their use require from the driller skill and unlimited patience.

A stranger can form some idea of the difficulties of these fishing jobs, when he is told that it is quite an ordinary operation, to remove from a hole five and one-half inches in diameter and over one-quarter of a *mile* deep, a string of tools seventy feet long, weighing 2,400 pounds,

nearly filling the hole, and wedged so tightly that a ship's cable could not pull them loose.

The Macksburg field has had an unusual number of long and expensive fishing jobs, besides a great many of less note, mostly due to the wet drilling. It is said that there are probably two fishing jobs here to one in the Pennsylvania fields, and that at one time out of thirty-two drilling wells fourteen were fishing. If tools are stuck below the jars so tightly that they cannot be jarred loose, or if the upper part of the tools have become so wedged by stones or mud caving in, so that the jars do not work, it will not do to pull on the cable, but the tools must be speared loose, that is, the rocks and earth cut away from around them. For this purpose is used a tool called a spear, fig. 10 on plate IV, with very long thin blade, forty to sixty feet in length, its cross section being somewhat the shape of a crescent. Before putting this into the hole, the cable attached to the stuck-tools must be gotten out of the way. For this purpose a rope-knife, on the end of sucker-rods, is run down along the rope. When the knife reaches the top of the tools it is pulled up; the edge catches in the rope and cuts it off. The cable is then hauled out, another rope-socket put on, and a second "string of tools" made up by using an extra sinker-bar, jars and the spear. With this a space is slowly cut around the tools, the process being similar to drilling with ordinary bit, that is, first cutting with spear, then bailing out the fragments, and again spearing until at length the tools are free. Then the spear is taken off, and in its place is put some kind of socket to grasp the tools. What is known as a slip-socket is generally used here. This is a tool made to slip over the top of the loosened tools below, without catching, but on being drawn back two loose slips, with roughened surfaces on inside, are drawn inward, and wedging, securely hold the object between them. When the slip-socket has a good grip it stands jarring upward for a long time, so that even if the tools still stick, jarring may bring them out.

A horn-socket is used when there is no necessity of jarring. This is a circular tool with long conical hole in bottom. It is lowered over the top of the lost tool, and when the head of the tool once gets fairly wedged in this opening, it is held there by friction.

There are innumerable shapes of sockets depending upon the form of the object to be grasped.

There are also various devices for straightening up a lost tool, as a bit, which has fallen so slanting in the hole that a socket cannot get hold.

To recover the end of a rope broken in the hole there are rope-spears and grabs. The rope-spear is a straight bar with barbs pointing

upward along its sides. The grabs have two or three prongs with the barbs pointing inward and upward. These, when lowered into a mass of rope in the hole and then pulled back, catch into the coils and draw the rope out.

To get hold of joints of tubing or casing which has broken apart, tools are made which slip inside, and when pulled up increase in diameter, thus pressing outward and holding the pipe by friction against its inner surface. If the casing is fast and will not start, then it can either be slit up by a casing-splitter allowing it to collapse, or it can be cut off at any point by a casing-cutter.

The only good illustrations of the commoner fishing tools, as yet seen, are those given in the catalogue of the Oil-Well Supply Co. Line. From this some idea of their ingenuity can be had, but to fully appreciate the engineering feats, which are by them accomplished, a person must visit the drilling-wells of the oil regions.

Measuring the Drilling-Well.

A measurement of the depth below surface of any stratum, can, of course, only be made while the drill is passing through it, that is, as it in turn forms the bottom of the well. As quick time is of the first importance, and the operations of drilling go on continuously day and night, unless interrupted by accident, until the well is down, the measurement must be done quickly, and at the moment the drill is not at work, whether this happens during the day or at the most inconvenient hours of the night. It is evident that the drillers are the only persons who can be ready at hand, and on them depends the accuracy of all ordinary measurements, as well as the determination of each change of rock. As a general thing, the exact depth of any rock, excepting the oil-bearing sands, is a matter of small interest to the driller, he being satisfied with a very general knowledge that the rocks are, as he terms, "regular."

The method in most common use is called the derrick measurement, the distance to bottom of well being obtained at any time by measuring the drilling-cable on the derrick, as the tools are being lowered into the hole. The exact distance from bull-wheel shaft up over crown-pulley down to floor of derrick must be known. This is about 140, 160, or 180 feet, according as the derrick is nine, ten or eleven girths high.

When the tools hang in the derrick just entering the hole in the floor, a string is tied on the cable at the bull-wheel shaft. The tools are lowered till this string has gone up over and come down to the floor,

then another string is tied on near the shaft, and so on, till the tools are close to the bottom; the last fraction of derrick-height being measured by a five-foot stick. In the ordinary course of drilling, such measurements are made every few days, or when some well-known stratum is reached. Intermediate distances are estimated by the number of screws run since the last measurement.

It will be seen at once, that errors can come in by slipping of string, stretching of the rope, and mistakes in number of screws, any one of which would vitiate the record for scientific purposes; and even should the rock layers be identified in order as the drill passes through them, still there is liability of inaccuracy in depth and thickness. On striking the top of oil-bearing sand, or passing through the bottom of it, more care is taken that there may be no error as to the right place to put the torpedo. Most producers, therefore, use a steel tape or round wire measuring-line, marked every fifty feet, and tested. The flat tapes are more common than round wire, it being thought that they stretch less. In a deep hole, say one-third of a mile, filled with salt-water, it requires some skill to tell when the weight on the measuring-line has reached bottom, and without great care even the steel tape may thus deceive.

Shooting.

As soon as possible after the drill has passed through the oil-sand, the well is torpedoed, to open up fissures in the sand and increase the flow. For this purpose nitro-glycerine is used in quantity, varying from thirty to eighty quarts, or, at $3\frac{1}{3}$ pounds per quart, from 100 to 267 pounds; 160 to 200-quart shots have been reported. The amount used is governed largely by the capacity of the shells; that is, the torpedo case is as long as the good oil-sand is thick, and usually as large as can be safely inserted.

The torpedo consists usually of one or more tin shells filled with nitro-glycerine, and provided with suitable firing-head. The shells are from three to five inches in diameter, five inches being as large as can be used. The length of the shell depends upon the size of the shot. A five-inch shell will hold 4.08 quarts to the foot, and as 100 pounds is about as much as can be safely lowered at once, shells of this diameter are not over $7\frac{1}{2}$ feet long. The nitro-glycerine comes from the factory in square tin-cans, holding six or eight quarts, or twenty to twenty-five pounds each. They are transported in a light buck-board buggy, fitted for the purpose.

The seat of the carriage is made to tip back, uncovering a box divided into sixteen or twenty compartments, each padded to hold snugly a

can of nitro-glycerine. On the side of the buck-board are two Y's, in which the tin shells are strapped, and behind are carried the reels for lowering and firing. The carriage is drawn over the rough roads by a pair of good horses, at a speed that seems to a stranger decidedly dangerous. Arriving at the well, a shell is placed in the top of the casing, fastened there, and filled by pouring in the nitro-glycerine from the cans. Then being hooked to the end of the wire lowering-line, the shell is slowly lowered. When it rests at bottom, the hook disengages, and the line is reeled up. For a large shot several shells are used, one resting on top of another. The lowest shell is supported up to the proper height in the sand by a small tin tube called the "anchor."

After the first shell has been lowered, the measuring-line should be run in to be certain that the shell is at the right place, and has not struck on some projection in the wall at a point above where it is intended to be.

Exploders.

There are several ways of exploding the nitro-glycerine after it has been put into position into the well. The method in longest use is by what is known as the "go-devil." For a go-devil shot, the top shell has in its upper part a small perforated tin tube containing three or four little anvils, one above the other, each carrying a water-proof percussion cap. The nitro-glycerine, when the shell is full, flows in around these caps through the perforations in the small tube. On the upper cap rests an iron rod, fastened to a flat plate above the shell. When this shell is in place and the lowering-line reeled up, an iron casting called the "go-devil" is dropped into the well. This falling, strikes upon the iron plate, the shock sets off the percussion caps, exploding the nitro-glycerine. On plate IV, fig. 12, is shown a drawing of the shells in common use. This represents two shells in the well, the one above resting on the lower, which is held up in the hole by the long tail-piece or anchor. In the top of the upper shell is seen the firing plate steadied, by two wires, and above this the go-devil about to fall on it. Both shells are represented as broken near the middle, in order to shorten the cut.

If the go-devil does not set off the shot, because either it did not fall with sufficient rapidity through the salt-water or mud had fallen on the plate, the shot must be "squibbed". The squib is a small shell, holding a quart or more of nitro-glycerine. It is lowered until it rests on the shells in the well, and is then fired by letting a hollow weight run down on the wire line. Guided by the line this weight strikes a firing head similar to that used on larger shells, and the explosion of the squib sets off the larger bulk of nitro-glycerine below.

The method of exploding now most in favor is by a time fuse. The top shell is not provided with firing-head, but is made like the other shells. The squib which carries the time-fuse is made hollow in the centre to hold about a pint of nitro-glycerine. Into this nitro-glycerine is inserted the end of a long fuse terminating in a large fulminate cap. The fuse is cut of length to burn two to three minutes, according to depth of well. It is wound around the hollow centre piece, enclosed in a tin covering, and then the interstices filled with sand. When all is ready, the projecting end of the fuse is lighted and the squib dropped into the well. The fuse is cut of such length that the squib shall fall upon the shells before exploding, thus setting them off.

In old wells, which have been shot several times, there must be a large cavity, and in this the shells of another shot may fall or be inclined so that the go-devil cannot strike the firing-plate. It is for this class of wells that the fuse is most used. The time-squib has the advantage over the go-devil-squib that it does not require that a firing-line shall be used and left in the hole, where it is not only lost, but may help to form a "bridge" or plug in the hole.

The explosion takes place at such great depth that at surface there is felt merely a slight jarring of the ground, and a report about as loud as a pistol shot is heard. In a few seconds, however, the enormous force of the explosive is shown by the flow of oil shooting high above the derrick, bringing out stones, water and fragments of the tin shells. This first flow is allowed to go into the air in order that the well may be blown out clean. As soon as possible tubing is put in and connections made to the tank, to save the following flow.

A good flow does not always follow a shot. Sometimes the shattered fragments, instead of being thrown out, become wedged and jammed together, completely choking up the hole and forming a "bridge." In this case the drilling-tools must be put in and the bridge cut out. This is a disagreeable undertaking, since the well is full of foul oil and poisonous burnt products of nitro-glycerine, which are occasionally thrown out, covering men and machinery.

Explosives.

For the torpedo various explosives have been tried, but nitro-glycerine has supplanted them all. Its fluidity is not such an objection as in other mining operations, because the torpedo is always used in a vertical hole, and not, as in ordinary blasting, in any position. For wells outside the oil-regions, and at a distance from the nitro-glycerine factories, black powder or some of the various dynamites are used, and in the oil-field itself attempts have been made to introduce rack-a-rock,

an explosive consisting of chlorate of potash and di-nitro-benzole, which are mixed when ready for use, but the producers do not believe that anything is as quick and powerful as nitro-glycerine, and say that all other explosives tend rather to break the sand into fragments near the torpedo, thus choking up the hole, and do not open up such far-reaching fissures.

One of the greatest objections to nitro-glycerine is the danger in handling the vessels in which it has once been put, and especially the tin cans in which it is carried. Many fatal accidents have occurred from these cans having been left hidden in the underbrush near a well where nitro-glycerine has been used, and being carelessly handled by boys or ignorant and reckless persons who have found them.

Manufacture of Nitro-glycerine.

The manufacture of nitro-glycerine is largely dependent upon the production of petroleum, and is closely connected with it, since not being received by railroads and other carriers, the fluid must be made within or close to the oil-producing areas.

The process is quite simple, requiring little capital or skill, intelligence and proper caution being the principal requisites.

The plant consists of one or more cheap sheds, with plenty of openings for ventilation, a few small wooden tanks, a mixing-tub, good water supply, and abundance of ice. The operations of manufacture are merely the pouring pure glycerine into a mixture of nitric and sulphuric acids, and the washing out the excess of acid.

The mixed acid is shipped by the manufacturer of chemicals in iron drums holding 1,500 pounds each. These drums are cylindrical in form, three and one-fourth feet long by two and one-fourth feet diameter. They are made of boiler-plate, riveted and protected from external injury by two rings of cart-iron placed near the center, on which they can be rolled. They are filled and emptied by a hole in the side, which is closed by screwing in an iron plug. The pure glycerine or oil, as it is termed, comes in small kegs. To "make a run" a tank of acid is emptied into the mixing-tub. This is a cylindrical iron vessel, open at top, about three feet in diameter, and four feet deep, made of riveted iron plates.

It is placed inside of a large wooden tank, and the space between the walls, about eight inches, is kept filled with ice. In the center of the mixing-tub is a vertical iron shaft, carrying horizontal iron arms or stirrers. The arms are made to revolve by beveled gears at top of shaft, connecting it with horizontal shaft leading to crank at one side. A

long thermometer is immersed in the acid, with its top projecting above the wooden cover. The acid, by exposure to air in process of transferring from tank to mixer, becomes heated, and must be left to cool. When the temperature has come down to about 60°, the stirrer is set in motion, and the glycerine is allowed to flow into the acid in a small stream. The acid at once begins to heat, and the thermometer must be watched. If the temperature gets above 80°, the stream of oil is shut off till the mercury goes down, the stirring going on all the time.

The oil is run in as rapidly as is possible without sending the temperature up to a dangerous point, since the yield of nitro-glycerine is said to be larger, the more quickly the run is made. When oil, equaling in weight $\frac{1}{8}$ of that of the acid, has been run in, the mixture is "drowned," that is, a plug in the bottom of the mixing-tub is drawn out, and the whole contents dumped into a tank, holding fifty to sixty barrels of cold water. The nitro-glycerine settles to the bottom, excepting a small film which floats on top, but can be made to settle by lightly patting with a flat stick. The water is first drawn off, and then the nitro-glycerine is allowed to run into a smaller wooden tank. Here it is washed to free it from acid, for about three hours, by letting flow through it a stream of water heated, if possible, to 140° F.

When clean, it is packed in tin cans or earthenware jars, and stored in safes or vaults until wanted.

From 1,500 pounds of the mixed acids, and 188 pounds of glycerine, a yield of 380 pounds of nitro-glycerine is considered good. In damp and rainy weather the yield is less, since the moisture in the air dilutes the acid; the heat thus generated also delays the operation.

In the Macksburg field there are two manufacturers, each making probably a ton or more of nitro-glycerine per month. The price is 65 cents per pound, or $2.00 a quart, exploded in the well; the price at Bradford, Pa., and adjoining places, is $1.00 a quart in well. The men who make the nitro-glycerine and put in the torpedoes are paid $75.00 to $100.00 per month. On account of the poisonous nature of the material all those who handle it have painful headaches and sickness, from which continued contact not only does not give immunity, but even increases the severity.

Tubing and Packing the Well.

As soon as the flow caused by the shot has ceased, preparations are begun to put in the tubing. A few of the largest wells will flow for a time through the casing, usually, however, there is not sufficient gas and oil to do this, excepting just after a shot, and tubing, extending from the top to bottom of the well, is inserted to diminish the area which the

gas and oil must fill. In the Macksburg field the tubing and packer serve still another purpose, that of keeping the salt-water, which here comes into the wells in inexhaustible supply, from forcing its way into the oil-sand, and driving back the oil or injuring the permeability of the rock. In other fields the casing usually shuts off all the water, but here it merely keeps the upper rocks from caving, and the tubing must supply this deficiency. The customary size of tubing, both for flowing and pumping-wells is two inches internal diameter, but for the smaller wells at Macksburg 1½ or even 1¼-inch is used, not only on account of lower cost, but also because if the tubing is just large enough to deliver the oil, the flow is more regular, and the tubing is kept cleaner, the paraffine not being so apt to be deposited and to finally fill the tubing as when the intervals between the flows are longer.

The cost of tubing in September, 1885, was thirteen cents per foot for 2-inch, eleven cents for 1½-inch, and about nine and one-half cents for 1¼inch. The tubing is made in lengths of eighteen to twenty feet, with screw-thread on each end; two pieces are screwed together by a coupling which is sold with the tubing already screwed on one end of each length.

The Packer.

The packer is a device for filling the space around the tubing at a point above the oil-sand to confine the oil and gas so that they can escape only through the tubing, and at the same time it keeps all the water from the oil-sand. There have been innumerable styles of rubber packers invented and patented; the general principle, however, is the same. A hollow cylinder of rubber, smooth or ribbed on the outside, and as large as can be put into the well, is held above and below by flanges connected by a slip-joint. This arrangement is put near the lower end of the tubing at such a distance from bottom that the rubber shall come against a firm stratum close above the oil-sand. When the tubing rests on the bottom of the well, the weight of its upper part forces the top flange upon or, if conical, into the rubber, distending it horizontally against the sides of the well, making a gas and water-proof joint. The packer most largely in use at Macksburg, is quite simple, is unpatented, made at Marietta and resembles in outline the Armor packer most nearly. It has a smooth rubber cylinder, ten or twelve inches long, upper flange is conical, slip-joint is below the rubber.

Anchor.

The portion of the tubing below the packer is called the anchor. To allow oil and gas to flow freely into the tubing, the anchor is usually

made of perforated pipe, or of short pieces of tubing connected by T's, the third hole of the T being left open.

Putting in the Tubing.

To tube a well there is required, in addition to the rig and power already in use for drilling, a tubing-line, snatch-block, pair of tubing-elevators, tongs and the tubing provided with anchor and packer (or pump-barrel for a pumping-well).

The elevator is a contrivance (fig. 15, plate IV) which is placed around the tubing below the coupling, grasping it loosely, and allowing the tubing but not the coupling to slip through. It is provided with a pair of handles or bails, into which to put the hook of the snatch-block.

One end of the tubing-line, which is often a piece of old cable 300 feet long, is attached to the bull-wheel shaft, the other end is carried up over the crown-pulley, the slack pulled down, and then the end fastened to the top of the derrick. In the bight thus formed the snatch-block is placed.

The hook of the snatch-block is put into the bails of the elevator, which has been placed on the anchor piece, the engine started and the piece is hoisted and lowered into the casing, until the elevator rests across the casing head. Then the other elevator is fastened to the joint of tubing carrying the packer. This is lifted until it swings over the anchor-piece, the two are screwed together by wrenches, the whole hoisted to relieve the lower elevator. This is taken off and the tubing is lowered until the second elevator rests in turn upon the casing-head.

The first elevator has, meantime, been put on a piece of tubing. This is now hoisted, screwed into the top of the length in the well, lifted a few inches, the lower elevator removed, and the string of tubing again lowered.

This operation is repeated until the whole of the tubing has been put in, the tubing being all the time hung from the coupling of the piece last screwed on. When the tubing rests on the bottom of the well, from its upper end it is continued by a square turn and two-inch pipe called the "lead-pipe," to the tank.

While putting in the tubing the well usually flows, drenching the men and wasting the oil. To avoid this inconvenience and loss a *disk* is often used. This is a thin sheet of brittle composition metal, placed in the tubing just above the packer, preventing any oil flowing up. When the well has been tubed, successfully packed, and connections made with the tank, an iron rod is dropped into the tubing. This shat-

tering the disk, a flow immediately follows. In large wells, however, the tubing cannot be forced down and a packer made tight when a disk is used, on account of the enormous gas-pressure.

Flowing Wells.

All the deep wells, that is, those drilled into the lowest oil-bearing sandstone at Macksburg, are flowing, and when once tubed and packed, require no further outlay, excepting for gauging the tanks and general supervision, for months, and perhaps for a year or more, unless some accident occurs.

The gas-pressure has never been measured in this field, but as it can lift a column of oil 1,900 feet in height, it must be, at least, over 700 pounds to the square inch.

Oil-wells do not flow continuously and quietly like a spring of water, but by paroxysms, which occur with some regularity. At all times more or less gas is escaping from the well; at certain intervals, however, its free passage is choked by accumulating oil, then the flow of gas diminishes and the pressure below increases, until finally it lifts the column of oil and ejects it with great violence. The gas then flows uninterruptedly, until the oil collecting in the tubing again interferes with its passage, and a second flow takes place. The great expansion of the gas attendant upon this sudden release of pressure, causes an intense cold, so that pipes have been, even in the hottest days in summer, covered with frost or completely frozen up at times where a small amount, of water had collected. On large gas-wells the apparatus used for reducing and equalizing the pressure is kept heated by a gas flame to prevent the freezing at this point of the water and "weaker" oils.

Paraffine in the Tubing.

On account of this intense cold, or because of the escape of the lightest oils as gas, the solvent power of the crude is diminished, or from other causes not fully understood, solid paraffine separates from some oils, and is deposited on the inside of the tubing, gradually filling it up and preventing the flow.

To remove this paraffine numerous devices are employed. The simplest plan is to shut in the well; that is, to turn a stop-cock on the tubing so that no gas can escape for twenty minutes or an hour, or as long as it is thought safe, there being danger of too great pressure lifting the tubing and unseating the packer. When it is judged that sufficient pressure has been obtained, the cock is quickly opened and the rush of gas which follows will usually throw out much of the paraffine·

Sometimes it is shot out in lengths of a few feet, looking like huge candles, and again it is pushed out, falling in long coils upon the derrick floor or into the tank.

If this does not succeed, the tubing must be cleaned by a *spear* or a paraffine auger. The spear is a straight iron rod hung on the sand-line. This is lowered into the tubing, and when it has settled as far as it will go, the paraffine is jerked out as rapidly as the engine can pull it. This operation is repeated again and again, each time the spear settling a little lower, and the rope cutting and bringing out slushy paraffine, which is lavishly distributed over men and machinery. Sometimes there is put on the lower end of the spear one or more leather caps, so made that when going down they close against the spear, but on being withdrawn, open and scrape against the sides of the tubing.

This is called *agitating* a well. The theory is, that by the rapid withdrawal of the spear a partial vacuum is formed, and the gas, rushing to fill it, throws out the loosened particles of paraffine.

The *auger* is a long flat blade, twisted in a spiral. This is fastened to the sand-line by a swivel, so made that when the auger is descending it can twirl about and work its way into the paraffine, but on hauling up, a catch on the swivel holds so that the auger cannot reverse its motion without twisting up the rope. This it cannot do, as the rope is under tension, and the auger pulls out the paraffine precisely as a carpenter's auger will clean the hole which it has bored when jerked out.

The last resort, if the paraffine cannot be got out any other way, is to pull out the tubing, disjoint it and blow steam through the joints, cleaning them thoroughly.

No care is now taken to save or utilize this crude paraffine, but it is shoveled out of the derrick, and finally softened by the sun, it soaks into the ground.

The pulling of the tubing from a dry hole, i. e., one where water does not stand on the packer, is not a serious matter. Two men with a good engine can take out and put back the tubing in half a day, but in the Macksburg field, where upon the pulling of the packer a column of heavier salt-water, 1,000 feet or more in height, will be thrown at once upon the oil-sand, it is a question of great importance whether the tubing, if plugged, can be pulled without greatly injuring the well. There have been but a very few wells whose tubing has been reset, and in these there were other causes which might have prevented their flowing freely afterward.

Pumping Wells.

Whenever there is not enough gas to throw the oil out of a well, it must be pumped. This is the case in the Macksburg field with wells obtaining their oil from sands above the salt-water sand.

For a pumping-well the tubing is preferably 2 inch to give space inside for the pumping-rods, or, as they are generally called, "sucker-rods."

The *pump* shown on plate IV, fig. 13, with a portion of side cut away, showing the valves, is on the principle of the ordinary lifting-pump. It is screwed on the lower end of the tubing, and being a long cylinder, forms a continuation of it. The rod which moves the upper valve works inside the tubing, so that the whole apparatus does not take up any more space in the well than the pipe for flowing.

A packer is not generally used; the water which comes in from above the oil-sand is pumped out with the oil, and is settled out and drawn off from under the oil in the tank. An ordinary packer can be used if there is enough gas to lift the valves. There is, however, a pumping-packer made expressly to shut off water from pumping-wells. This packer is not "set out" by the weight of the tubing, but slips loosely on the tubing, resting when in use upon a collar. It is compressed by a line of smaller pipe, which goes down by the side of the tubing and makes a direct connection through the packer. This shuts out the water and yet allows the atmospheric pressure to reach the pump.

When the water comes into a well, especially a small one, in notable quantity, there is economy in shutting it off by one of these means.

The pump-cylinder, known as the "working barrel," is made of iron or brass, is three and one-half or five feet long, and one and three-fourth inches internal diameter. Ball valves are used exclusively.

The upper and lower valves may be either single or double; that is, one ball valve is placed over the other, so that if one ball does not work the other may.

The upper or working valve is packed by leather cups pressed out for that purpose, or where sand is very troublesome in cutting the packing, rope cups are used. The screw and the plunger-working barrels are largely displacing the old forms of pump, because of the greater length of time during which they can be used, since they do not have any cups or rope-packing to wear out.

The tubing for a pumping-well is inserted in the same manner as for a flowing well, excepting that a working barrel is put above the anchor. Instead, however, of letting it stand on the bottom of the well, some producers prefer to hang the tubing from the casing-head by using

a ring which catches under the last coupling of the tubing, and rests upon the casing-head.

After the tubing is all in, the sucker-rods, with working-valve on lower end, are lowered into it. The sucker-rods are of hard wood, octagonal or round cross-section, $1\frac{1}{8}$-inch in diameter, and are 20 to 25 feet in length. Some producers use the twisted iron rods, as taking up less room in the tubing. On each end iron joints are riveted to the wooden rods, and steel joints welded on the iron by which the rods are screwed together.

On the upper end of the sucker-rods is put the polished rod which passes through a stuffing-box screwed into the top of the tubing. The pipe leading to the tank is screwed into a T, just below the stuffing-box. The top of the polished rod is fastened to the end of the walking-beam by an adjuster by which the rods can be lowered or taken up, bringing the working-valve to its proper position.

All wells are pumped by the oscillating walking-beam, but there is a variety of ways in which power is transmitted to it from the engine. Formerly every well had its boiler and engine, and man to attend them, but with small wells and cheap oil this was found to be too expensive, and ways of pumping several wells at once were invented There are three methods in use, by which one man can pump several wells, located not far apart. The first is by having a boiler centrally located, and from this running steam pipes, enclosed in plank-boxes packed with sawdust, to an engine at each well. This is the plan in general use throughout the Bradford, Pa., field. Its disadvantages are the cost of engine and steam-pipe and the loss of heat by radiation in the long steam lines. It has the advantage, however, that the rods and tubing can be pulled at any time, and the well overhauled as the engine is ready in position.

In the second method power is transmitted to the walking beams of the several wells from one engine placed near the boiler, by means of long rods provided with suitable angle-knees for changing direction of pull.

The engine runs an oscillating pull-wheel which gives horizontal movement to the rods radiating to the various wells. The rods are suspended above the ground at suitable distances by ropes attached to the top of posts, or by rocking-beams resting on the surface.

The pull-wheel draws the rods in one direction, and on the return oscillation the weight of the sucker-rods hanging from the walking-beam draws them back.

This is the method in use at Macksburg ; it is the least expensive.

As for rods almost any long stick will do, such as old sucker-rods, poles, iron, gas-pipe, etc.

The third method is in general use in West Virginia, where the hills are so steep and sharp that it is difficult to hang and counterbalance the rods. Here an endless wire-rope, usually $\frac{9}{16}$-inch diameter, running continually in one direction, transmits the power from the engine to a groove-wheel, driving the walking-beam of each well. The rope passes from the large groove-wheel, nine to ten feet in diameter, in the engine-house out overhead to the groove-wheel of the first well, then deflected by a sheave, five feet in diameter, runs to next well, and so on until it has completed the circuit of eight or ten wells before returning to the engine house. The rope is supported about every 150 feet by running over a five-foot sheave, and can be deflected in any direction. Twenty-five to thirty shallow wells are thus pumped by one engine, by having three or four independent circuits, each with its wire-rope, and pumping first one lot of wells for a few hours, then another.

Total Cost.

The total cost of a flowing-well, 1,600 feet deep, at Macksburg, is estimated as follows:

Rig, complete	$350
Boiler, 20-horse-power	450
Engine, 15-horse-power	210
Drilling, 1,600 feet, at 75 cents per foot	1,200
Casing, head, etc	250
Tubing and pipe to tank, 1,700 feet, at 13 cents	221
Shot, 80 quarts, at $2.00 per quart	160
Tank, 250 barrels	100
Teaming, connections, tank-cover, etc	59
Total	$3,000
Engine and boiler can be sold at	500
Net cost	$2,500

For a pumping-well, add about $100 for sucker-rods, pump, polished rod, stuffing-box, etc. The boiler and engine must be left at well for pumping, or power obtained in one of the ways mentioned.

Production.

The production of the Macksburg field for month of September, 1885, was 2,700 barrels a day (42 gallons to barrel), from about 250 wells, or an average of a little more than 11 barrels a well a day. In this field a well is rated large which starts flowing at 200 or 250 barrels per day,

and at end of month, or so, has only settled to 50 or 75 barrels. A good well should flow at first 75 to 100 barrels per day and settle to 15 or 25 in a month or two. One which starts at 10 barrels is considered poor, and from three barrels down, a "dry-hole".

Value of Production.

Sales of production are not frequent and, as a general thing, the prices are not made public, but $500 per barrel is a common estimate; that is, a well producing 5 barrels a day would sell for $2,500, one doing 8 barrels $4,000, etc. At this price, a well, if its production did not decrease, would pay for itself in less than a year and a half, at $1.00 per barrel, or in 2 years at 70 cents per barrel.

The amount produced by a well, however, is constantly decreasing; when the well is new the falling off is rapid, but after a few weeks it settles to a flow, which from the few old wells (down 8 to 12 months) is nearly uniform from month to month. If the falling off was, say 5 per cent., a month, that is, each month's production being 95 per cent. of the previons month, a well at this price would pay for itself in 3 years, or at $4.00 per barrel, in two years, oil being at a dollar. The total value of the field, figured on this basis (only $4.00 per barrel), is over a million dollars, or an average of about $330 per acre, including iron and machinery.

Gravity of the Oil.

As is generally the case, the oils from the different sands differ in color and gravity, and even the oils from wells sunk into the same rock show slight variations.

In the Macksburg field at present there are none of the heavy gravity oils produced. The oils from the pumping wells, all in the so-called "700-foot sand," are dark-green, and range in gravity from 44° to 46°. The deep oil is lighter green, almost yellowish in tinge, is very clear and its gravity, contrary to what is usual, is greater than that of the shallow oil, the fresh oil ranging from 37° to 41°, varying greatly on account of the gas.

Tanks at Wells.

Each new well is provided with one, sometimes two 250-barrel wooden tanks. These tanks are circular, a little smaller at top than at bottom, so that the iron hoops can be driven down as the wood shrinks, and the joints begin to loosen. The staves are 8 feet long; bottoms, up to 16 feet diameter. The tanks are enclosed in rough board

houses to protect them from the weather, and as an additional precaution against rain-water leaking into the tank and injuring the oil by formation of B. S., are covered with a deck of matched boards.

The oil flows into the tank through the cover from the pipe leading from the well. Ten inches above the bottom is inserted the 2-inch pipe by which the oil is run out into the line of the transportation company. Close to the bottom is a wooden plug to let out any water coming in with the oil from a pumping-well.

In cold weather the oil becomes stiff, and to thin it and allow the water and sediment to settle out it must be heated before it can be run into the line. This is done by steaming, best by a steam coil, sometimes, however, by blowing steam directly into the oil and drawing off the condensed water below.

After the well has settled to a nearly unvarying daily production, its oil is usually turned into the same tank with that of other wells near by on the same lease. This tank is placed in a convenient spot, usually in the valley, where it can be readily inspected and steamed when necessary. There is an advantage in running the oil of several small wells together, in that the tank is more quickly filled, and there is consequently less loss by evaporation. The tanks for the largest wells and for the production of several wells together are made often of capacity of 600 barrels.

When a tank is connected to the pipe line of the transportation company, and each time afterward that its hoops are driven, it is carefully measured and its capacity computed for each one-eighth inch in depth. Then at any time, by measuring with a stick marked off into feet, inches and fractions, called the gauge-pole, the contents of the tank can be known.

From this way of measurement it has become customary to speak of a well's production in inches. In ordinary conversation a man will say that his well does 3, 5, or 8 inches, as the case may be, the inch being understood, unless otherwise stated, to mean one inch in depth in a 250-barrel tank, which is about two and one-half barrels, or more exactly, two and three-quarters barrels at bottom of tank, and two and one-quarter at top.

Running Oil.

In all the producing districts of any importance, both in Pennsylvania and New York, as in Ohio, the crude oil is transported from the tanks of the producers to those of the refiners by pipe-lines belonging almost exclusively to one large corporation, the National Transit Co., a branch of the great Standard monopoly. The pipe-lines are laid from

each tank and converging toward some conveniently located pump-station, usually in the valley, form a perfect network over the surface of the oil country. The collecting lines are all two inches internal diameter. On the pipe close to the tank is put a stop-cock, which is kept closed and fastened by a padlock that oil may not be run back into the tank or the line tampered with by mischievous persons.

These lines empty into iron tanks of 20,000 to 30,000 barrels capacity, located near the pump-station. When a producer's tank is nearly full he notifies the agent of the pipe-line and a gauger is sent to run the oil. The gauger inspects the oils, notes the temperature, sees that water is not standing in the tank high enough to get into the line, measures the depth of oil, then opens the cock, allowing the oil to run out. He then walks along the line to see that there are no leaks, down to the iron tank at the pump-station, sees that the oil is flowing all right, walks back, and when the oil in the tank has run down sufficiently, closes and locks the stop-cock, again measures the depth of oil in tank, gives to the well-owner or person in charge a memorandum of these measurements and reports them at the office of the line.

If the oil will not run out by gravity it is forced out by a little "donkey" steam-pump belonging to the pipe-line, hauled there and set up each time near the tank, or the oil is drawn out by a suction-pump permanently located at the pump-station.

Oil in the Line.

When the producer's oil has been run into the lines of the National Transit Co., the exact amount is calculated from the gauger's memorandum, allowance made for sediment and temperature, if necessary, and the amount is credited on the books of the company to each person having an ownership in the oil; that is, the royalty, usually one-eighth, is first taken out and placed to the credit of the owner of the mineral right, then the balance distributed in the designated proportion to each individual, if several parties are operating together, or to the firm as a whole, according to the wishes of the persons interested. The oil then becomes part of the general stock of the Transit Co., and the credit balance can be sold or transferred at any time at its then market value, which, of course, is constantly fluctuating. Before it can be transferred, however, from one account to another, all charges against it for storage must be paid either in money or in its equivalent of oil. The storage charge is $12.50 per month for a 1,000-barrel, and in addition to this there is the "general average" deduction if there should have been any loss of oil by fire or otherwise during the time the account was open.

That is, whenever an iron tank is burned, or by other accident, as by bursting of lines and tanks, oil is lost, the amount wasted is deducted pro rata from each account; for instance, should there be just 30,000,000 barrels of oil in the care of the line, and a tank holding 30,000 barrels is burned, each person is charged at the rate of one barrel for every thousand to his credit.

Iron Tanks.

The large iron tanks into which the producer's oil first flows, are called working-tanks. They are usually in pairs; when one is full the new oil is turned into the other, the first being meanwhile gauged and then emptied. From the working-tanks the oil goes, if not directly to the refineries, to storage-tanks in various parts of the country. The storage-tanks are similar in appearance to the working-tanks, ranging in capacity from 22,000 to 37,000 barrels. All of these iron tanks are cylindrical in form; they are from eighty-five to ninety-five feet in diameter, with sides twenty-two to thirty feet high. The bottoms are flat and rest directly upon the ground.

To build an iron tank a circular grade is plowed and scraped, the firm earth very carefully leveled, and a gutter dug to keep it dry. The bottom plates are then brought onto the grade, placed in their proper position upon wooden horses or trestles, which support them about three feet above the ground, giving space for the workmen to get under while riveting.

When the bottom has been riveted, caulked and inspected, the angle-iron put on, and the first ring of plates forming the side firmly riveted in place, the partly-made tank is lowered onto its grade. To do this the workmen go under, knock off the legs of the trestles from the centre out, leaving the tank-bottom suspended on blocking around the edge. Care is taken to remove all sticks of wood under the tank, and then two gangs of men working on opposite sides, by long levers, gradually take out the blocking and lower the tank to its final position. The plates to form the second ring are then put on, then the third, and thus till the top angle-iron has been riveted in place. According to their height the tanks have five, six or seven rings of plates, the iron of the lowest ring being thickest, each ring diminishing in weight toward the top, the plates of the last ring and those of the bottom being of equal gauge. Each plate of the side is a little over four feet high and eight feet long; the lowest ring weighs fifteen pounds to the square foot. There are about 600 days' iron-work on the tank; that is, a gang of fifty men can put one up in two weeks. After the iron-workers are through

the tank is turned over to the carpenters to build the roof. The roof is conical, with rise of five feet from circumference to center. It is supported independently of the sides upon posts standing upon planks laid on the bottom of the tank.

The roof-joists run radial and the boards concentric to the tank, so that sector-shaped panels can be taken out at a time when necessary to renew the roof. This board roof is covered by sheet-iron, lapped and nailed down at the joints. The tank is provided with hatchways in roof and wooden steps up on the outside, closed about half-way up by a gate. When finished the tanks are painted with red iron paint.

The Macksburg pipe-line has in the field thirteen iron tanks, with an aggregate capacity of over 300,000 barrels.

Most of these have been cut down and brought from the declining Pennsylvania fields. The cost of the tanks, new, in Fall of 1885, was about nineteen cents per barrel of capacity; old, nine to ten cents, or for a new 25,000-barrel tank, $4,750, and an old one, $2,500. To cut down, ship, and reset a tank of this size costs about $3,000, there being sometimes 200 days' iron-work in patching in addition to the other labor.

The iron tanks are measured and their contents estimated for each fraction of an inch in depth, allowance being made for the liquid displaced by the roof-supports. There are usually four openings in the roof through which the gauge-rod can be put, so that if the bottom settles somewhat the average depth can be taken. All the tanks are gauged and inspected each day.

To ascertain the condition of the oil at various depths, since it tends to separate into layers in the tank, an instrument called a "thief" is used. This is a small box like arrangement, either cylindrical or square, containing one or more compartments, closed by tightly-fitting doors or slide.

It is lowered open into the tank to the depth at which a sample of the oil is wished; when it is full, the slide is closed and the thief is taken out. Usually one side is made of glass, so that the oil can be seen directly. By using a long thief with compartments one above the other, several samples can be taken at once. In this way the formation of B. S. is detected and means can be taken to prevent it, and the amount of water and sediment in the bottom of the tank can be accurately determined.

Transporting the Oil.

From the storage-tanks oil is transported to the seaboard or inland refineries, to some localities wholly by pipe, to others in tank-cars on the railroads. The pumps, by which the oil is forced from place to place,

are usually duplex-plunger Worthington's, or similar styles. The pressure given to the oil by these pumps is frequently up to 1,500 pounds per square inch. They are stationed at convenient points to the producing field, and at intervals on the long trunk-lines which lead to large cities. The pump-stations are comparatively well-built and permanent, consisting of boiler-house, engine or pump-house, and usually a machine-shop for repairing the pumps and cutting pipe. At each important station the pumps are duplicated, so that if one pump is disabled, or its valves need repacking, the other pump can be used at once.

For railroad transportation, the well-known cylindrical tank-cars are used. These hold about 100 barrels each; they are filled through the man-hole in top of dome, and emptied by a valve in the bottom. To fill the tank-cars, there are provided what are known as loading-racks, usually placed near the pumping station. The rack consists of a long wooden trestle, supporting a pipe which runs parallel to the switch-track, upon which the cars are run, and at a height of about three feet above their domes.

From this pipe, at intervals of a car length, branch out swing-pipes of adjustable length. When the oil-train is run alongside, the branches are swung out, their ends inserted into the domes of the cars and the oil allowed to flow in, thus loading the whole train at once.

From the Macksburg field there are two pipe-lines, the Macksburg Pipe Line, belonging to the National Transit Co., having a three-inch line to Parkersburg, and the two-inch pipe to Lowell, owned by Mr. Geo. Rice. The Macksburg Pipe Line handles about 80 per cent. of all the oil; part of this, probably one-half, is pumped directly to Parkersburg, and the balance is shipped by rail to Cleveland. The pump-station, iron tanks and loading-rack are on the C. & M. R. R., near Elba station. There are two line pumps, each having a capacity of about ninety barrels per hour when working, against a resistance of 900 pounds to the square inch, and also one suction-pump for taking the oil from wells on the flats.

CHAPTER VIII.

THE TRANSPORTATION, USES AND MODES OF USING NATURAL GAS.

By Emerson McMillin.

In the preceding chapters the reader has been told of the geographical locations where natural gas has been found; of the geological horizons that must be pierced to obtain it; of its probable and varied origin; of the reservoirs in which it is stored; of its chemical composition, and of the theories that should probably govern in the location of wells bored for gas, with descriptions and illustrations of rigs, power and tools used in the search for natural gas—the great desideratum of almost every town and city in our land.

Wells may be properly located, the holes successfully drilled, and a flow of gas obtained; but, to be utilized, the gas must be conducted through lines of tubing, from the casing at the well to the burner, fire or furnace, where it is to be consumed. This may be a short or a long distance; if the former, probably but few difficulties will be encountered; if the latter, there are many problems to solve if the work is to be done expeditiously, safely and cheaply.

Systems of Transportation.

The earliest system of tubing or piping natural gas was that of bored logs. This mode has been practiced in the Kanawha Valley for more than half a century. The logs are usually cut from trees twenty to thirty inches in circumference, and the holes bored from two to four inches in diameter, and from end to end through the center of the log. The sections are cut from six to ten feet long. The end of one log is tapered to a spigot, and driven into the reamed-out end of another log. These conduits answered their purpose quite well in their day, but the high-pressure gas from wells now in use in other parts of the country could not be utilized with a pipe-line made in this manner.

Very efficient gas-pipes for conducting manufactured gas, are made in places in the state of Michigan, by boring out tamarack logs, which

are afterwards coated, inside and out, with pitch or asphalt. Twelve or fifteen years ago this class of pipe was a strong competitor of cast-iron pipe for gas-mains. The great reduction in the cost of iron pipe, and the uncertainty attending the probable duration of the wood pipe, have caused the use of the latter to be almost entirely discontinued.

Cast-iron pipes, in sizes above two inches, are used almost exclusively for conveying manufactured gas. This remark applies to the United States, and to most other countries. The French engineers, however—especially in Paris—use tubing which is made by coating heavily with hydraulic cement thin sheet-iron, bent to the shape and size desired. This pipe has been used in this country even for heavy-pressure water-mains, but the use here has been so limited that an opinion as to its merits cannot be given.

Wrought iron tubing, rolled to the size required, is now being used by a few engineers as mains for conveying manufactured gas.

The first cost is greater than is the cost of cast-iron, and the supposition is that the wrought-pipe will not last so long.

This supposition is probably correct; and yet, with an experience of twenty years, chiefly with cast, but partly with wrought-iron gas-mains, I have never seen either kind, wrought or cast, removed because of oxidation, except when the conditions of the soil were unusual. Small service-pipes to consumers rust out quickly—in some soils in less than two years—but the iron of the small pipe is very thin, and a little oxidation will go through it.

The iron in the larger pipes is thicker and, when a thin coat of oxide is formed on the outside, it apparently protects the surface from further oxidation. Neither wrought nor cast-pipe conducting gas will oxidize on the inside.

The high-pressure pipes in use in and about the city of Pittsburgh—the present center of natural gas utilization—are almost exclusively of wrought-iron. Many miles, however, of larger sizes, ten to twenty-four inches in diameter, of cast-iron pipe have been laid in that city during the last two years. This cast-pipe is not expected to carry a pressure exceeding ten pounds per square inch. By enlarging the area of the cast-pipe, and by properly constructed appliances, to be described further along, the pressure is reduced from 200 pounds, as it sometimes is in the high-pressure wrought-pipe, to ten pounds on entering the cast-pipe.

Much excitement prevailed in and about Pittsburgh during the year following the introduction of natural gas, growing out of the accidents that occurred through defective system of transportation. The escape of the gas—which there possesses no odor—caused houses to be blown

up, and many persons to be dangerously injured, and, in some instances, causing loss of life. The dangers became so great that the matter was taken into Court, and an effort made to correct the evil. In the equity proceedings between the city of Pittsburgh and the Fuel Gas Company et al., the Court appointed a Commission of five intelligent persons to make a thorough and exhaustive investigation of the questions involved.

The report of this Commission has been made public, and it imparts much valuable information. The parties giving testimony before the Commission were experts, engineers, pipe-layers, chemists and mechanics, and the testimony given was oftentimes of the most confusing and conflicting character. While there were many questions of detail to be settled by the investigation, there were two principal questions to be determined that transcended all others. First, how high a pressure can be carried in the pipes without endangering life and property; and, second, to how low a pressure may the gas be reduced without increasing its cost beyond the point where a profit, commensurate with the risk of the business, can be made on the money invested.

It was estimated, at the time of the investigation, that about 60,000,000 feet of natural gas was being used in Pittsburgh every twenty-four hours. This equaled 2,500,000 feet every hour.

The consumption, however, would not be regular, and the capacity of the supply-pipes probably had to be equal to a maximum delivery of 5,000,000 feet per hour.

The testimony before the Commission indicated that experts were inclined to believe that, respecting pressure, the old established practice of companies supplying manufactured gas ought to be taken, as a rule, for the government of the natural gas companies. The Commission did not take this view of the question, but advised that a pressure, not exceeding ten pounds per square inch, be allowed in the pipes in the city. The pipes that were laid for transporting natural gas in the city, previous to the report of the Commission, were not laid much, if any, below a depth of three feet. As might have been foreseen, this practice resulted—in the winter season—to an almost constant disturbance of the pipes by frost, with enormous leakage and frightful destruction of property, and even loss of life. The apparent necessity for a better and safer system for transporting this dangerous fluid set inventors to work, and scores of plans and devices have been suggested, some possessing merit, but, so far, none seem to entirely meet all phases of the demand. Some governors of great value have been invented. They control the pressure of the gas, preventing its rising above the desired point in the pipes; and if, from any cause, the gas ceases to flow, and the fires or

light are extinguished, the gas cannot again pass into the premises without its being turned on by *hand*. This is probably the most useful invention yet brought out in connection with the question of natural gas supply.

To prevent leakage at joints, many plans have been suggested.

The ends of wrought-pipes have been faced, and the threads made long enough, so that the pipes butted together in the middle of the socket, practically making a ground-joint. Another plan was to chamfer the ends of the pipes, and screw them in against a gasket of lead in the center of the socket. Either of these plans would doubtless have given a tight joint, had the temperature of the pipe always remained about the same as when put down; but, at the shallow depth at which the pipes were laid, the joints were failures. Screw-joints, calked with copper wire, also failed for the same reason. Had these joints been made with the pipe at about 40 degrees temperature, and the pipe buried six or seven feet in the earth, it is probable that they would have been practically tight, even at 200 pounds pressure. Pipe should not be laid in long, straight lines, but should form, when down, a slightly wavy line to give room for contraction without destruction of joints. Much of the trouble from leaky joints has been attributed to the variation of the pressure. The registering sheets show this to be constantly varying—generally to but a slight degree, but occasionally the pressure drops down to five pounds, and then suddenly leaps to fifty or sixty pounds per square inch. This change of pressure cannot cause leakage to any great extent, with any of the joints described. The increase of pressure must give an increase of temperature, and that in turn give expansion of the pipes and a consequent tightening of the joints.

To prevent accidents from leakage, various contrivances have been tried. One company in Pittsburgh laid some lines of pipe the usual depth in the ground, and then laid a clay pipe along the top of this pipe, with an occasional outlet leading to and up through a lamp-post, where a light was kept constantly burning—the idea being to have the gas leaking from the iron pipes to follow along in the terra cotta pipe and escape at the lamp-post, and there be consumed. This, of course did not prevent leakage, but prevented accidents from leakage. Opinions differ as to whether this plan is entitled to much confidence, the weight of opinion seeming to be against it. Another plan suggested is that of laying the main below frost, then putting a sleeve over each joint of the main, and this sleeve to be tapped for, say a three-quarter-inch pipe, and this pipe to be attached to a two-inch pipe, running parallel to and lying over the main pipe, the upper pipe being buried just under the street pavement. The gas leaking from the joint

would enter the sleeve surrounding it, pass up the small pipe into the two-inch, which pipe shall have stop-cocks or valves between the joints, and, by the aid of these valves, the leaky joint can be quickly located. The objects sought to be accomplished are, first, to prevent the escape of gas into cellars, and second, to be able to locate the leaks with rapidity and certainty, with the minimum disturbance of the streets.

Owing to the difference in the composition of the gases, that which is found in the vicinity of Pittsburgh, and also of Findlay, is much more difficult to transport, without leakage, than is that of the oil regions of Pennsylvania. In the first place, its specific gravity is much less, and, second, the absence of oily residuals, which, in the gas-oil regions, aids in closing up the small interstices of the pipes and joints. The specific gravity of the Pittsburgh gas is given as .557; that of Findlay, Ohio, at .585, and that of Bradford, Pennsylvania, as .850—air being 1.000.

Measurements of Quantity, etc.

The extensive use of natural gas at the present time, and the long distances it is being carried, makes the question of a convenient formula for calculating the flow of gases through pipes one of much importance. There is a popular rule in use by gas managers that will occasionally be found convenient to use by those unable to calculate accurately, with the formula in use by engineers, the sizes of pipe required. This general rule is, that

First. The discharge of gas will be doubled when the length of pipe is only one-fourth of any given length.

Second. The discharge of gas will be only one-half when the length of pipe is increased four times.

Third. The discharge of gas will be doubled by the application of four times the pressure.

While these rules are good enough when applied to the short distances of lengths of pipe, and to the slight changes of pressure that occur in the distribution of manufactured gas, they have little value when applied to the great variations in length of pipe, and pressure, that are met with in transporting natural gas.

The following formula is in general use for calculating the discharge of gas through mains:

q=quantity of gas, in cubic feet, per hour.
l=length of pipe in yards.
d=diameter of pipe in inches.
h=pressure, in inches, of water (or "head").
s=specific gravity of gas—air being 1.

$$q = 1{,}350\, d^2 \times \sqrt{\frac{h\ d}{s\ l}}$$

i. e., multiply the pressure, in inches, of water, by the diameter of the pipe, also in inches; divide the product by the specific gravity of the gas, multiplied by the length of the pipe in yards; extract the square root of the quotient, which root, multiplied by the constant quantity, 1,350, and the square of the diameter of the pipe in inches, gives the number of cubic feet discharged in one hour.*

Example: It is required to find the number of cubic feet of gas, of the specific gravity of .57, which will be discharged in one hour, from a pipe six inches in diameter and three miles (5,280 yards) in length, under a pressure of ten pounds per square inch. This pressure equals, say, 276 inches, or the pressure given by a column of water 276 inches high.

Thus: $(h\ d) = 6 \times 276 = 1{,}656.$

$$\left(\sqrt{\frac{h\ d}{s\ l}} = \frac{1{,}656}{.57 \times 5{,}280}\right) = \sqrt{.5502};$$ the square root is .74.

$$1{,}350\ d^2 \sqrt{\frac{h\ d}{s\ l}} = 1{,}350 \times 36 \times .74 = 35{,}964$$ cubic feet per hour.

To make this as clear as possible to the non-technical reader, the example will be still further explained.

Thus: h (the head or pressure) = 276 inches; this multiplied by 6 (the diameter, in inches, of the pipe) = 1,656; this divided by .57 (the specific gravity of the gas), multiplied by 5,280 (the number of yards in three miles), = .5502. The square root of the last sum equals .74 ×, and this times 1,350 (constant quantity), and this again × 36 (the square of the diameter of the pipe) = 35,964, or the cubic feet of gas discharged per hour.

Second example: It is required to ascertain the quantity of gas, of the specific gravity of .6, which will be discharged through a pipe 8 inches in diameter and 10 miles in length, under the initial pressure of 75 pounds per square inch. Ten miles equals 17,600 yards, and 75 pounds equals 2,070 inches of water pressure, or head.

Thus: $(h\ d) = 8 \times 2{,}070 = 16{,}560.$

$$\left(\sqrt{\frac{h\ d}{s\ l}} = \frac{16{,}560}{.6 \times 17{,}600}\right) = \sqrt{1.5277},$$ the square root being 1.252.

$$1{,}350\ d^2 \sqrt{\frac{h\ d}{s\ l}} = 1{,}350 \times 64 \times 1.252 = 108{,}172$$ cubic feet discharged per hour.

* Recent observations on natural gas lines have shown, as suggested by the author on the preceding page, that this formula is not reliable for high-pressures and long lines. It gives too low results. This subject is discussed in the succeeding chapter.—E. O.

Third example: Required to ascertain the quantity of gas, of the specific gravity of .5, that will be discharged through a pipe 10 inches in diameter and 30 miles long, under an initial pressure of 200 pounds per square-inch. Thirty miles equals 52,800 yards, and 200 pounds pressure equals 5,520 inches of water head.

Thus: $(h\ d) = 10 \times 5{,}520 = 55{,}200.$

$$\left(\sqrt{\frac{h\ d}{s\ l}} = \frac{55{,}200}{.5 \times 52{,}800}\right) = \sqrt{2.0909}, \text{ the square root being } 1.44.$$

$$\left(1{,}350\ d^2 \sqrt{\frac{h\ d}{s\ l}}\right) = 1{,}350 \times 100 \times 1.44 = 194{,}400 \text{ cubic feet, or the}$$

quantity that will be discharged in one hour.

Formula for ascertaining pressure required for the discharge of a given quantity of gas, through a given length and size of pipe:

$$h = \frac{q^2\ sl}{(1{,}350)^2\ d^5}, \text{ or } h = \frac{q^2 \times s \times l}{1{,}350^2 \times d^5}$$

Fourth example: Required to ascertain the pressure necessary to pass 100,000 cubic feet per hour, through eight miles (14,080) yards of 6-inch pipe; specific gravity of gas, .5.

Thus: $100{,}000 \times 100{,}000 = 10{,}000{,}000{,}000 \times .5 = 5{,}000{,}000{,}000 \times 14{,}080 = 70{,}400{,}000{,}000{,}000 \div (1{,}350 \times 1{,}350 \times 7{,}776) = 4{,}968$ (nearly), the pressure required (in inches of water), which equals 180 pounds per sqnare inch.

This may be stated thus:

$$\frac{10{,}000{,}000{,}000 \times .5 \times 14{,}080}{1{,}822{,}500 \times 7{,}776} = 4{,}968 \text{ inches, or 180 pounds, in which}$$

the ten billions is the square of the quantity, the decimal, *five*, the specific gravity, the fourteen thousand and eighty the length of pipe in yards, and the seven thousand seven hundred and seventy-six is the fifth power of the diameter of the pipe.

Fifth example: Required to ascertain the pressure necessary to discharge 20,000 feet of gas per hour; specific gravity, .58, through 3,000 feet (1,000 yards) of 3-inch pipe. Formula same as for preceding example.

Thus: $20{,}000 \times 20{,}000 = 400{,}000{,}000 \times .58 = 232{,}000{,}000 \times 1{,}000 = 232{,}000{,}000{,}000 \div (1{,}350 \times 1{,}350 \times 243) = 524$ inches, or 18.9 pounds pressure.

To ascertain the diameter of a pipe, which will discharge a given

quantity of gas, through a given length of pipe, under known pressure, we have the formula:

$$d = \sqrt{\frac{q^2\ sl}{(1{,}350)^2\ h}}$$

Sixth example. Required the diameter of a pipe which will discharge 50,000 feet of gas per hour, of the specific gravity of .7, through ten miles (17,600 yards) of pipe, with an initial pressure of eighty pounds (2,138 inches).

Thus: $\frac{2{,}500{,}000{,}000 \times .7 \times 17{,}600}{1{,}822{,}500 \times 2{,}208} = \sqrt[5]{7{,}654} = 6—.$

$50{,}000 \times 50{,}000 = 2{,}500{,}000{,}000 \times .7 = 1\ 750\ 000{,}000 \times 17{,}600 = 30{,}800{,}000{,}000{,}000 \div (1{,}350 \times 1{,}350 \times 2{,}136) = 7{,}654$, which equals the fifth power of six inches, the required diameter of the pipe.

In gas engineers' hand-books are published tables, showing the discharge of gas through pipes ranging in size from a half-inch to thirty-six inches in diameter, in lengths of from ten yards to ten thousand yards, and under pressure from one-tenth of an inch to four inches. Believing that smaller pipe than three inches should not be used for mains, and that natural gas will seldom be used at a pressure below one inch, the discharge of gas through smaller sizes than three-inch, with less pressure than one inch, will not be given. The discharge through larger sizes of various lengths, and at different pressures up to 2.5 inches, are given.

These tables are calculated on the basis of .400 for the specific gravity of the gas, which is less than the specific gravity of any natural gas of which we have an analysis. The *quantity of gas of any other specific gravity, which will be discharged in one hour, may be ascertained by multiplying the quantity indicated in the table by* .6325 (*the square root of* .400), *and dividing by square root of the specific gravity of other gas.*

The quantity that will be discharged at any other pressure may be ascertained by multiplying the quantity indicated in the table by the square root of the new pressure, and dividing by the square root of the pressure given in the tables.

These low pressures and short lengths will be applicable to the distribution of natural gas where municipal or other authorities prohibit high-pressure service in thickly populated portions of towns and cities. Even these low pressures are higher than should be used when consuming gas for illumination. Natural gas, as usually found, being of low illuminating power, should be consumed at a low pressure, and a pressure of 2.5 inches is probably as great as should be used when gas is consumed for heating purposes.

Diameter of Pipe, 3 Inches.

Length in yards	100.	250.	500.	1,000.
Quantity discharged in cubic feet, per hour, with 1 inch pressure	3,317	2,102	1,482	1,052
Quantity discharged in cubic feet, per hour, with 1.5 inches pressure	4,070	2,576	1,823	1,288
Quantity discharged in cubic feet, per hour, with 2.0 inches pressure	4,702	2,965	2,102	1,482
Quantity discharged in cubic feet, per hour, with 2.5 inches pressure	5,261	3,317	2,345	1,652

Diameter of Pipe, 4 Inches.

Length in yards	100.	250.	500.	1,000.
Quantity delivered in cubic feet, per hour, with 1 inch pressure	6,826	4,320	3,046	2,160
Quantity delivered in cubic feet, per hour, with 1.5 inches pressure	8,359	5,270	3,737	2,635
Quantity delivered in cubic feet, per hour, with 2.0 inches pressure	9,655	6,091	4,320	3,046
Quantity delivered in cubic feet, per hour, with 2.5 inches pressure	10,800	6,826	4,817	3,413

Diameter of Pipe, 6 Inches.

Length in yards	250.	500.	1,000.	1,500.
Quantity delivered in cubic feet, per hour, with 1 inch pressure	11,858	8,408	5,929	4,860
Quantity delivered in cubic feet, per hour, with 1.5 inches pressure	14,580	10,308	7,290	5,970
Quantity delivered in cubic feet, per hour, with 2.0 inches pressure	16,816	11,858	8,408	6,853
Quantity delivered in cubic feet, per hour, with 2.5 inches pressure	18,808	13,268	9,380	7,679

Diameter of Pipe, 8 Inches.

Length in yards	250.	500.	1,000.	1,500.
Quantity delivered in cubic feet, per hour, with 1 inch pressure	24,365	17,280	12,182	9,900
Quantity delivered in cubic feet, per hour, with 1.5 inches pressure	29,894	21,082	14,947	12,200
Quantity delivered in cubic feet, per hour, with 2.0 inches pressure	34,560	24,365	17,280	14,083
Quantity delivered in cubic feet, per hour, with 2.5 inches pressure	38,621	27,302	19,267	15,725

Diameter of Pipe, 10 Inches.

Length in yards	500.	1,000.	1,500.	2,000.
Quantity delivered in cubic feet, per hour, with 1 inch pressure	30,105	21,330	17,400	15,050
Quantity delivered in cubic feet, per hour, with 1.5 inches pressure	36,855	26,055	21,300	18,500
Quantity delivered in cubic feet, per hour, with 2.0 inches pressure	42,660	30,105	24,570	21,300
Quantity delivered in cubic feet, per hour, with 2.5 inches pressure	47,655	33,750	27,540	23,760

Diameter of Pipe, 12 Inches.

Length in yards	500.	1,000.	1,500.	2,000.
Quantity delivered in cubic feet, per hour with 1 inch pressure	47,433	33,631	27,500	23,800
Quantity delivered in cubic feet, per hour with 1.5 inches pressure	58,320	41,212	33,600	29,250
Quantity delivered in cubic feet, per hour, with 2.0 inches pressure	67,262	47,433	38,800	33,600
Quantity delivered in cubic feet, per hour, with 2.5 inches pressure	75,233	53,071	43,351	37,519

Diameter of Pipe, 16 Inches.

Length in yards	500.	1,000.	1,500.	2,000.
Quantity delivered in cubic feet, per hour, with 1 inch pressure	97,459	69,120	56,600	49,000
Quantity delivered in cubic feet, per hour, with 1.5 inches pressure	119,577	84,326	69,120	60,100
Quantity delivered in cubic feet, per hour, with 2.0 inches pressure	138,240	97,459	79,488	69,120
Quantity delivered in cubic feet, per hour, with 2.5 inches pressure	154,483	109,209	89,164	77,068

Diameter of Pipe, 20 Inches.

Length in yards	500.	1,000.	2,000.	3,000.
Quantity delivered in cubic feet, per hour, with 1 inch pressure	170,640	120,420	85,300	69,800
Quantity delivered in cubic feet, per hour, with 1.5 inches pressure	208,980	147,420	102,300	85,300
Quantity delivered in cubic feet, per hour, with 2.0 inches pressure	241,380	170,640	120,420	98,800
Quantity delivered in cubic feet, per hour, with 2.5 inches pressure	270,000	190,620	135,000	110,200

Diameter of Pipe, 24 Inches.

Length in yards	1,000.	2,000.	3,000.	4,000.
Quantity discharged in cubic feet, per hour, with 1.5 inches pressure	284,781	201,000	165,000	142,000
Quantity discharged in cubic feet, per hour, with 2.0 inches pressure	328,536	232,621	189,000	165,000
Quantity discharged in cubic feet, per hour, with 2.5 inches pressure	367,770	260,091	213,000	184,000
Quantity discharged in cubic feet, per hour, with 3.0 inches pressure	402,456	284,731	232,621	201,000

Diameter of Pipe, 30 Inches.

Length in yards	4,000.	5,000.	7,500.	10,000.
Quantity discharged in cubic feet, per hour, with 2 inches pressure	234,000	210,000	172,000	149,000
Quantity discharged in cubic feet, per hour, with 2.5 inches pressure	263,000	234,000	192,000	166,000
Quantity discharged in cubic feet, per hour, with 3.0 inches pressure	287,955	257,000	210,000	182,000
Quantity discharged in cubic feet, per hour, with 4.0 inches pressure	331,695	298,000	243,000	210,000

Diameter of Pipe, 36 Inches.

Length in yards	1,000.	3,000.	5,000.	10,000.
Quantity delivered in cubic feet, per hour, with 1 inch pressure	530,000	303,000	234,000	166,000
Quantity delivered in cubic feet, per hour, with 2 inches pressure	741,830	428,000	332,000	234,000
Quantity delivered in cubic feet, per hour, with 3 inches pressure	908,042	524,880	407,000	288,000
Quantity delivered in cubic feet, per hour, with 4 inches pressure	1,049,760	605,361	468,892	332,000

Below is given the weight and cost of the various sizes of both wrought and cast-iron pipe, the prices being about those prevailing at this time. The cost of excavating and back-filling trenches, where the pipes are laid not less than four feet deep, will be from ten to fifteen cents per lineal foot, depending largely upon the character of the soil. If the back-filling must be tamped down solid, and pavements taken up and relaid, the cost may run up to double the sums named. These estimates are for laying sizes of pipe below ten inches in diameter. The cost of trenching for ten-inch and larger, will be increased in proportion to the area of the cross-section of the trench. If cast-iron pipe is used, and the joints made with lead, the cost per foot for lead, yarn and labor, will be about as given in the table below. The cost of laying wrought-iron pipe, where the joints are screwed together, is quite insignificant, aside from trenching and back-filling:

Weight of Cast-Iron Pipe.

Inside diameter in inches.	Thickness of metal in inches.	Weight of 12 ft. lengths in pounds.	Weight of 100 feet in pounds.	Weight of 1,000 feet in pounds.	Weight of one mile in pounds.	Weight of five miles in pounds.	Weight of ten miles in pounds.
3	$\frac{5}{16}$	160	1,330	13,300	70,200	351,000	702,000
4	$\frac{5}{16}$	208	1,730	17,300	91,340	456,700	913,400
6	$\frac{7}{16}$	360	3,000	30,000	158,400	792,000	1,584,000
8	$\frac{5}{16}$	540	4,500	45,000	237,600	1,188,000	2,376,000
10	$\frac{9}{16}$	725	6,000	60,000	316,800	1,584,000	3,168,000
12	$\frac{5}{8}$	1,000	8,333	83,333	440,000	2,200,000	4,400,000
16	$\frac{11}{16}$	1,465	12,200	122,000	644,160	3,220,800	6,441,600
20	$\frac{3}{4}$	1,980	16,500	165,000	871,200	4,356,000	8,712,000
24	$\frac{7}{8}$	2,700	22,500	225,000	1,188,000	5,940,000	11,880,000
30	1	3,950	32,900	329,000	1,737,000	8,685,000	17,370,000

Weight and Cost of Lead, Labor and Yarn, in making Joints.

Inside diameter of pipes in inches.	Depth of bowl in inches.	Depth of yarn in inches.	Depth of lead in inches.	Weight of yarn in pounds.	Weight of lead in pounds.	Cost of labor in cents.	Total cost for each joint.	Cost of joints in 100 feet.	Cost of joints in one mile.
3	4.0	$2\frac{3}{8}$	$1\frac{5}{8}$	.....	2.75	10	$ 25	$2 00	$105
4	4.0	$2\frac{1}{4}$	$1\frac{3}{4}$	.175	4 00	12	32	2 56	135
6	4 0	2	2	.250	7.00	15	50	4 00	212
8	4.0	$1\frac{7}{8}$	$2\frac{1}{8}$	.350	10.50	20	75	6 00	318
10	4.5	$2\frac{1}{4}$	$2\frac{1}{4}$	.50	14.50	25	1 00	8 00	424
12	4.5	$2\frac{1}{8}$	$2\frac{3}{8}$	.70	18.50	30	1 25	10 00	530
16	4.5	2	$2\frac{1}{2}$	.80	28.50	35	1 70	13 60	720
20	5.	$2\frac{3}{8}$	$2\frac{5}{8}$	1.20	35.50	40	2 20	17 60	933
24	5.	2	3	1.50	48.00	45	2 95	23 60	1,250
30	5.	$1\frac{1}{4}$	$3\frac{3}{4}$	1.80	60.00	50	3 60	28 80	1,526

Wrought-Iron Pipe.

Inside diameter, in inches.	Price, black, per foot.	Price, galvanized, per foot.	Thickness of iron in inches.	No. of threads per inch of screw.	Weight per foot—pounds.	Weight per yard—pounds.	Weight per mile—pounds.
1½	$ 08	$ 14½	.145	11½	2.68	8.04	13,080
2	10	18	.154	11½	3.61	10.83	19,000
2½	16	282	.204	8	5.74	17.22	30,270
3	20	372	.217	8	7.54	22.62	39,775
3½	25	498	.226	8	9.00	27.00	47,520
4	31	60	.237	8	10.66	31.98	56,300
4½	37	75	.246	8	12.34	37.02	65,150
5	45	90	.259	8	14.50	43.50	76,560
6	55	1 20	.280	8	18.76	56.28	99,000
7	74	.....	.301	8	23.27	69.81	122,850
8	1 02	.....	.322	8	28.18	84.54	148,800
9	1 37	.....	.344	8	33.70	111.10	195,500
10	1 76	.....	.366	8	40.06	120.18	211,500
11	2 13	.....	.375	8	45.02	135.06	237,700
12	2 40	.....	.375	8	49.00	147.00	258,720
13	2 87	.....	.375	8	54.00	162.00	285,100
14	3 33	.....	.375	8	58.00	174.00	306,200
15	3 70	.....	.375	8	62.00	186.00	327,300

When we consider that an average of more than ten per cent. of the gas manufactured by gas companies is lost by leakage, and that, too, when the pressure used ranges only from three-quarters to four inches of water column, or one-third to one and three-fourths oz. per square inch, we must expect, under any circumstances, even where the best pattern of joints are made with the greatest care, that the quantity of leakage under the heavy pressure of natural gas wells will be very great—a very much larger quantity per mile of main pipe, though generally a smaller per cent., owing to the greater volume that will be passing

through the pipes conveying natural, than those conveying artificial gas.

Cast-iron pipes for the conveyance of natural gas should be tested by hydrostatic pressure, up to at least 300 pounds pressure on the square inch, rapping the pipe with a hammer while under pressure. The pipes are usually cast in sections of twelve feet, exclusive of the bowl or hub.

Weight of cast-iron pipe may be calculated by the following formula:

$$W=2.45\ (D^2-d^2),$$

where D=outside diameter of pipe in inches;
d=inside diameter of pipe, in inches;
W=weight of a lineal foot of, pipe, in pounds.

Example: Required, the weight of one foot of 8-inch pipe, metal half-inch thick. Square of outside diameter, (9 inches $\times$ 9 inches)=81 inches, less square of inside diameter (8 inches $\times$ 8 inches)=64 inches, =17, $\times$ constant, 2.45,=41.65, or the weight in pounds of one foot of 8-inch pipe.

The bowls in cast-iron pipe are usually made in sizes of pipe from 3-inch to 8-inch, about 4 inches deep; 10 inch to 20-inch-pipe, 4½ inches deep; 20-inch to 30-inch pipe, 5 inches deep. The space for calking between outside of spigot, and inside of bowl, is about three-eighths of an inch, in pipes smaller than eight inches, and one-half inch in larger sizes. The weight of bead on spigot, and the bowl, will about equal the weight of one foot of pipe.

The ordinary bowl and spigot-joint for gas-pipe is made by driving into the joint, with a properly constructed calking-tool, hemp rope, until the space is from one-fourth to three-fourths filled. Then the remaining space is poured full of molten lead, which, after cooling, is driven up solid with a setting-tool.

The depth of lead should be increased for pressures higher than those used in pipes conveying manufactured gas. Many good gas engineers make joints in the cast-iron pipe with good hydraulic cement. With this kind of joint about the same quantity of hemp-packing is used as with lead. The yarn is thoroughly saturated and coated with cement mortar, and driven hard into the bowl, and the bowl filled in this way to about the usual depth—one-fourth to three-fourths of the total depth—and then the remaining space is filled with the cement. In a few hours the joint is tight, and will withstand, if the cement used is good, more pressure than the pipe itself. The cost of the cement-joints is much less than that of lead-joints.

There is one very serious objection to this mode of putting together

gas-mains; it is too rigid; there is no room for expansion and contraction; and any very great reduction in temperature must result in the breaking of the pipe. This difficulty may, in a great measure, be obviated by using lead in every fourth or fifth joint, which, if pipes are laid the proper depth, will give room for possible expansion and contraction.

While cast iron can, and doubtless will, be generally used for low-pressure, it should not be used for high-pressure mains.

To convey gas under a pressure of fifty to two hundred and fifty pounds on the square inch, only the best of lap-welded wrought-iron or steel pipes should be used. Where the threads are cut, the metal should be made thick, so that the pipe shall not be reduced in strength at that point. One source of great weakness is in the special fittings; they should all be made of the best malleable-iron or steel, and very much heavier than those generally found in the market. Not even the best wrought-iron or steel pipe should be laid without having been first subjected to a hydrostatic pressure up to at least four times as great as any pressure that it will be subjected to in use.

In conveying natural gas long distances under high-pressure, there should be two or more lines of pipe, connected at short intervals, with by-pass valves. Safety or blow-off valves should be attached at short intervals. In towns and cities there should be a complete net work of pipes, with valves at all intersections of streets, so that, in case of breaks in pipes, or accidents of any kind, a section of the line can be thrown out of use with a minimum of inconvenience to the users of gas.

The Commission at Pittsburgh, in its report to the Court, makes some recommendations which we feel ought to be given a place in this chapter: They say:

"There should be stop-valves located not over three thousand feet apart on all high-pressure mains, so that a line can be shut off in sections, in case of accident.

"A uniform pressure should be kept on each line.

"Each high-pressure feeder, to a low-pressure main, should have an efficient pressure-regulator, and, in addition thereto, not less than two blow-off valves, each of sufficient capacity to relieve the line of any excess of pressure.

"All low-pressure lines should be connected with each other, and, to the high-pressure mains, in such a manner as to form a circuit. If the lines are connected in this manner, with sufficient feeders from the high-pressure mains, and all dead ends avoided, the pressure we designate in the next finding as low-pressure will, in our opinion, be

adequate to supply all possible consumers of gas, except the large manufactories, which are provided for direct from high-pressure mains.

"A greater pressure than ten pounds should not be allowed on low-pressure lines.

"In each public building, located near a low-pressure main or mains, a mercury gauge should be placed, connected with the main or mains, and open at all reasonable hours to the inspection of citizens.

"All tees, angles, gates, etc., should be of the best in the market, and they, and all sleeves, should be covered with suitable boxes with perforated covers."

Manufactured Fuel Gas.

It is a common remark now that, should natural gas fail in its supply, the vast sums of money invested in conducting mains will not be lost, as the public, in many localities, will have become so accustomed to the use of gaseous fuel that they will never wholly return to the use of solid fuel, and that fuel gas will be generated from the slack and waste at coal mines, and be conveyed through the mains laid for conveying natural gas to manufacturing places, and for domestic use.

In this connection, numerous ideas are being insidiously cultivated by venders of patented processes for making fuel gas.

Pamphlets are circulated, in which claims are made respecting the quantities of gas that can be made from refuse coal, that have scarcely a semblance of truth in them. The writer has seen published statements, claiming that by the use of a newly-discovered process, from 100,000 to 200,000 (a good large margin) feet of 16-candle illuminating gas can be made from one ton (2,240 pounds) of coal. Now, when we consider that 100,000 feet of 16-candle gas will weigh about 3,300 pounds, and 200,000 feet 6,600 pounds, the absurdity of these statements is quite patent.

Lighting Properties of Gas.

So far, natural gas, outside of the immediate vicinity of oil pools, has not been successfully used, for lighting purposes, without enriching. That it has been used for illuminating purposes as it escapes from the earth, is well known, but the light is very inferior, being less than half that of good coal-gas.

Much time and money have been spent in efforts to convert the natural gas, by carbonization and dissociation, into a good illuminant. So far, nearly all these experiments have entirely failed, and none have been more than partially successful. Almost since the first days of gas-

lighting, authorities have generally conceded that the light derived from a gas is due to the heavy hydrocarbons present, chiefly from $C_2 H_4$. Dr. Frankland attributed *all* the light of coal-gas to three compounds of the ethylene series of gas, viz., ethylene ($C_2 H_4$), propylene ($C_3 H_6$), and butylene ($C_4 H_8$).

He contended that marsh-gas ($C H_4$) added nothing to the value of gas for lighting purposes, and that whatever diluent was used to carry the olefiant gas, the result would be about the same.

He, however, preferred hydrogen as a diluent, because of the innocuous character of the product of combustion. Dr. Percy F. Frankland, son of the earlier investigator, has made recent and more thorough investigations in this direction, and has clearly demonstrated that the quantity of light emitted from a gas-flame is materially affected by the nature or composition of the diluent; and of the three—hydrogen, carbon-monoxide and marsh gas—the latter was much the more valuable. These later conclusions are substantiated in the use of natural gas, which, in the vicinity of Pittsburgh, is almost pure marsh-gas (CH_4), with no ethylene present, and yet this gives light of about eight candles, or about half of common coal-gas. Dr. Frankland found that, with the 18-candle gas of one works, the ratio of illuminating power to ethylene was as 1.69 to 1, while in the case of 16-candle gas, at another works, it was 3.62 to 1—a difference of 114 per cent. Acetylene ($C_2 H_2$) is supposed to be present in very small quantity in coal-gas; notwithstanding the fact that it is present in such small proportions, it may, and probably does, have a decided influence on the production of light —its power for producing light being much above that of ethylene. Compounds of the benzene ($C_6 H_6$) series are also present in coal-gas, and notably so in the natural gas of Bradford, Pa. The value of a molecule of benzene for illumination is supposed to be six times as great as that of ethylene.

Berthelot, in 1875 and 1876, claimed to have ascertained that the gas in use in Paris contained no less than 3 to 3.5 per cent. of benzene, out of a total of 3.7 per cent of heavy hydro-carbons.

The correctness of his conclusions, however, has been seriously questioned. Another compound generally present in coal-gas, distilled or generated at high temperatures, is naphthalene ($C_{10} H_8$).

This is a troublesome compound to the gas manufacturer, as it seems almost impossible to prevent it forming a solid; and it is generally supposed to be kept in a liquid or gaseous condition only in the presence of other forms of heavy hydro-carbons.

Now, while natural gas, ordinarily, will not possess, in any appreciable quantity, any of these heavy hydro-carbons, is it not possible that

they are formed at the tip of the gas-burner? The carbon-monoxide and hydrogen in coal-gas are supposed to be largely consumed in the blue part of the coal-gas flame, and their combustion generates the heat that is essential to bring the carbon to incandescence above the blue flame, and from this incandescence we obtain the bright light rays. Natural gas, or much of it at least, contains no CO, and but little free H, and yet the blue part of the flame is larger than in good gas, but the lines that mark the boundary of the luminous and the non-luminous parts of the flame are not so distinct as they are in gas of high-illuminating power. May it not be that dissociation takes place near the tip of the burner, a portion of the hydrogen of the marsh-gas being set free to unite with oxygen of the air, producing part of the non-luminous rays, and higher compounds of hydro-carbons being formed by the remaining hydrogen and carbon? It may be said, if this supposition were true, as good light would or could be produced from marsh-gas as from coal-gas.

I can imagine two reasons why this may not be true: First, the dissociation with the formation of new hydro carbon compounds may occur in too small a quantity to produce the best results; and, second, the dissociation is a cooling process, and therefore the net results of the combustion is a lower temperature—less intensity of incandescence than when the heavy hydro-carbons are quickly heated by carbon-monoxide and free hydrogen. The fact that the illuminating power of natural gas is greatly enhanced by the use of argand burners, lends a degree of probability to the second reason given. It is claimed for the natural gas of Bradford, Pa., that it will produce a light of only ten candles when consumed in an open burner, yet when consumed in an argand it gives a light of twenty-four candles. The difference seems very great; but whatever the actual difference is, it must be due to the difference of temperature.

SUBSTITUTES FOR NATURAL GAS.

That the supply of natural gas will not last a great many years seems to be a generally accepted idea of most persons who have given the question serious consideration. That gaseous fuel from some source will continue to be extensively used, is as generally conceded. Should the supply of natural gas gradually fail during the next five or ten years, the failure would, doubtless, bring heavy losses to many individuals, firms and corporations. Still, the knowledge gained by the experience during those years would greatly benefit the public in general.

A very large per cent. of the operations in metallurgy are now made by the aid of gaseous fuel generated in Siemens and other producer furnaces. The great saving in this method of firing over that o

the direct utilization of the combustion of coal, is probably due, in a large degree, to the utilization of the waste heat in the regenerative chambers. Fuel gas, however, of this character—that is, made by the admission of air to the incandescent fuel—cannot be conducted long distances, except at an expense out of proportion to its value as a heat-producer. It is probable that a mixture of what is probably known as coal gas, water-gas and producer-gas will be the fuel-gas of the future for domestic use.

While there are many processes for the manufacture of water-gas that are in a measure successful, when using coke or anthracite coal with which to decompose super-heated steam, yet none of these invented processes have been wholly successful in the use of raw bituminous coal for this purpose. So long as coke or hard coal must be used, water-gas alone cannot be made cheap enough to become a competitor of direct firing with the soft coals in our state.

Comparative Value of Gases.

The following calculations will show the comparative values of the four gases—natural gas, coal-gas, water-gas, and gases from a Siemens or other producer-furnace. We will assume that the latter gas is made from the piles of slack coal lying in such vast quantities about coal mines, and that an approximate analysis of the slack would show it to be composed of—

Fixed carbon	55 per cent.
Permanent gas	15 "
Condensable matter, tar and soot	10 "
Water	10 "
Ash	10 "

Deducting the ash, the proportions are then, by weight—

Fixed carbon	61.11 per cent.
Volatile combustible matter	16.67 "
Water	11.11 "
Tar	11.11 "

The last three compounds will pass into the combustion-chamber in a measure unchanged. The fixed carbon will burn to carbonic oxide and carbonic acid. The best working will probably not convert more than 50 out of the 61.11 per cent. to carbonic oxide. Again, the best working will probably fail in combining all the oxygen of the air with the carbon, and this again will give an excess of nitrogen; but, excluding these excesses of deleterious matter, the gas from the producer will then have this composition:

Carbon monoxide	32.69	per cent.
Carbon dioxide	7 93	"
Nitrogen	61.82	"
Illuminating gas (H, CH_4, C_2, H_4, etc.)	3.24	"
Water vapor	2.16	"
Tarry vapor and soot	2.16	"
	100.00	"

The value, then, of each of the four gases that are now used being compared, will be, in heat units per pound of gas:

Natural gas	24,195
Common coal gas	22,968
Water gas	7,069
Siemens furnace gas	1,957

These values may appear very low to some of our readers, and this may need some explanation. I assume that if water-gas is to be used for heating alone it would not be purified of its carbonic acid, and I assume that it would be used at an average temperature of 60 Fahr., at which temperature it would carry about 1.5 per cent. of water. The same quantity of water would exist in the coal gas. The calculations are based upon the following composition of the several gases:

Natural gas (Findlay).	Coal gas.	Water gas.	Producer gas.	
Hydrogen	2.18	46.0	45.0	(In illuminating gas.)
Marsh gas	92.60	40.0	2.0	" "
Carbonic oxide	0.50	6.0	45.0	22.69
Ethylene	0.31	4.0	00 0	(In illuminating gas.)
Water vapor	0.00	1.5	1.5	2.16
Carbonic acid	0.26	0.5	4.0	7.93
Nitrogen	3.61	1.5	2.0	61.82
Oxygen	0.34	0.5	0.5	(Not considered.)
Hydrogen sulphide	0.20	00.0	00.0	0.00
Illuminating gas	0.00	00 0	00.0	3.24
Tar, soot, etc	0.00	00.0	00.0	2 16
	100.00	100.0	100.0	100.00

It is the common rule, in rating the value of any fuel, to calculate the weight of water that it will evaporate from a temperature of 212 de-

grees Fahr. In making calculations given above, I have assumed that, as the fuel in each case is gaseous, no excess of air will have to be brought into contact with the gas in order that perfect combustion may be obtained. In practice it is found that about 20 per cent. excess with gas, and 100 per cent. excess with solid fuel, is necessary. It is probable that a greater excess would be required to burn producer than to effect complete combustion with either of the other gases—this in consequence of the larger per cent. of nitrogen that it contains.

Again, in practice it is possible that coal-gas may be found to possess advantages over either of the other gases, and in a way that will not appear in a theoretical calculation.

It possesses more free hydrogen, and will therefore ignite at a lower temperature. Much of the ugly black smoke that it seen pouring out of smoke-stacks attached to furnaces of steam-boilers is due to the fact that, when the gases generated from the coal come in contact with the steam-boiler, they (the gases) are cooled below their point of ignition, and therefore escape unconsumed.

This being a well-known fact, it is reasonable to suppose that, in practice, the gas that ignites at a low temperature will produce better results, other things being equal, than a gas that ignites at a higher temperature.

The values, in heat-units, assigned to the several gases on the preceding page, were based on their comparison by weight. A comparison by volume will make a different showing.

Leaving off unimportant decimals, the specific gravities of the several gases are as follows:

Natural gas (Findlay)	.570
Coal gas	.400
Water gas	.570
Producer gas	1.000
Air	1.000

As natural gas has usually been found to have a temperature of about 40 degrees Fahr., the comparisons will be made on that basis:

One thousand feet of air, at 40 degrees Fahr., will weigh eighty pounds;
Then, 1,000 feet natural gas, specific gravity, .570 × 80 = 45.6 pounds.
" " coal " " .400 × 80 = 32.0 "
" " water " " .570 × 80 = 45.6 "
" " producer " " 1.000 × 80 = 80.0 "

Then, natural gas, 45.6 pounds × 24,195 = 1,103,292 units.
" coal " 32.0 " × 22,968 = 734,976 "
" water " 45,6 " × 7,069 = 322,346 "
" producer " 80.0 " × 1,957 = 156,560 "

The value of the producer-gas would be reduced more than ten per cent. by condensation, if the gas should be transported any considerable distance, or if cooled down to the temperature at which the other gases can and would be used.

Still another mode of comparing the heating-power of the several gases may be used, the results of which will have much more practical value than has either of the preceding modes of comparisons.

In these calculations we will ignore the heat lost by radiation, as it will be practically the same in each case (the higher the temperature, however, the more heat lost by radiation.)

We will assume that the work to be done is to evaporate water at 212 degrees Fahr. from an initial temperature of 60 degrees; that the air entering the furnace has a temperature of 60 degrees, and that the gases escape from the boiler flues to the stack at a temperature of 500 degrees, Fahr. We will assume that an excess of air, equaling 20 per cent. of the total required for combustion will be passed through the furnace.

Compcsition of Natural Gas.

	Per cent., by volume.	By weight.
Hydrogen, (H)	2.18	0.268
Marsh gas, (CH_4)	92.60	90.383
Carbonic oxide, (CO)	0.50	0.857
Olefiant gas, (C_2H_4)	0.31	0.531
Carbonic acid, (CO_2)	0.26	0.700
Nitrogen, (N)	3.61	6.178
Oxygen, (O)	0.34	0 666
Hydrogen sulphide, (H_2S)	0.20	0.417
	100.00	100.000

Oxygen will be required for the complete combustion of these gases, as follows:

Natural gas.	Oxygen required.	Resultant gases. Steam.	CO_2.	SO_2.	Nitrogen.
H— .00268 × 8 =	.02144	.02412			
CH_4— .90383 × 4 =	3.61532	2.03363	2.48553		
CO— .00857 × 4 — 7 =	.00490		.01347		
C_2H_4— .00531 × 3.43 =	.01821	.00684	.01668		
CO_2— .00700 ×			.00700		
N— .06178 ×					.06178
O— .00666 ×	.00666				
H_2S— .00417 × 1.415 +	.00589	.00221		.00785	
Totals... 1.00000	3.67242				
Oxygen 20% excess—.00666=	.72782				14.52079
Oxygen, 4.40024 × 3.3 = π					
	4.40024	2.06680	2.62268	.00785	14.58257

To reduce the results of the combustion of one pound to that of 1,000 cubic feet, we will multiply the several footings by the weight of 1,000 feet of the gas, thus:

Steam	2.06680 × 45.6	94.25 pounds.
Carbonic acid	2.62268 × 45.6	119.59 "
Sulphuric acid	.00785 × 45.6	00.36 "
Nitrogen	14.58257 × 45.6	664.96 "
Total product	19.27990 × 45.6	879.16 "

It may be well at this point to call attention to the fact that when pure *marsh-gas* is burnt the quantities of oxygen entering into the production of steam, and that entering into the production of carbonic acid, are of equal weight, the oxygen equaling two pounds in each compound for each pound of gas consumed, and aggregating 176.96 pounds for every 1,000 feet of gas consumed; that, to give the gas an excess of twenty per cent., a total of 20.78 pounds of air for each pound of gas will be required; this equals 919.3 pounds, or 11,491 feet of air for the combustion of 1,000 feet of gas.

Temperature of Combustion.

To ascertain the temperature produced by the combustion of 1,000 cubic feet of Findlay gas, we divide the total heat units by the sums of the resultant gases, multiplied by their specific heat:

Steam	94.25 × .4750	44.768750
Carbonic acid	119.59 × .2164	25.879276
Sulphuric acid	.36 × .2500	.090000
Nitrogen	664.96 × .2440	162.250240
	879.16 × .2650	232.988266

The total heat of 1,000 cubic feet of natural gas of the composition as shown on previous page, equals 1,103,292 units, and to this must be added the heat carried in by the air that furnishes the oxygen for combustion, thus: 200 pounds oxygen × specific heat (.218 × 60° temperature) = 2,616 units, and 664.96 pounds nitrogen × its specific heat (.244 × 60° temperature) = 9,744; total heat carried in, 11,860 units, + heat of combustion, 1,103,292, 1,115,152 ÷ 233 = 4,786 degrees Fahr.

In practice, of course, no such temperature would be attained, for, as before stated, all loss by radiation and convection is ignored in the calculation.

In order to determine how much water can be evaporated, at 212 degrees, from a temperature of sixty degrees, Fahr., we must multiply the total weight of the gases resulting from the combustion, viz., 879.16 pounds, by the specific heat of the escaping gas, .2650, which gives us 233, and this again × 500, which represents the degrees of temperature of the gases escaping from the boiler flues, the result being the heat lost, or carried away, viz., 116,500 units, deducted from the total heat of 1,115,152 units, leaves 998,652 units for work. To evaporate one pound of water at 212 degrees, from sixty degrees, requires 152 units, plus 966, rendered latent, or a total of 1,118 units. Then 998,652 ÷ 1,118 = 893.25 pounds of water; or, in round numbers, 1,000 feet of gas will produce heat equivalent to that required to evaporate 900 pounds of water.

The temperature that may be attained by the combustion of coal-gas, water-gas, and producer-gas, and their value for evaporating water, may be calculated in the same way as was that of natural gas; but, for the purposes of this work, it is not required that each should be given in detail; only the net results will be stated.

The composition of coal-gas is:

	By weight.	By volume.
Hydrogen	8.21	46.00
Marsh-gas	57.20	40.00
Carbonic oxide	15.02	6.00
Olefiant gas	10.01	4.00
Water	2.41	1.50
Carbonic acid	1.97	0.50
Nitrogen	3.75	1.50
Oxygen	1.43	0.50
Totals	100.00	100.00

The oxygen for the complete combustion of these gases, with the resultant products, is given in following table:

Coal gas.		Oxygen required.	Resultant gases.			
			Steam.	CO_2	SO_2	Nitrogen.
H	.0821	.6568	.7389	.....	.....	2.1674
CH_4	.5720	2.2880	1.2870	1.5730	.....	7.5504
CO_2	.1502	.0858	.....	.2360	.....	.2831
C_2H_4	.1001	.3432	.1287	.3146	.....	1.1326
H_2O	.0241	.....	.0241	.....	.....	.....
CO_2	.0197	.....	.....	.0197	.....	.....
N	.0375	.....	.....	.....	.....	.0375
O	.0143	.....	.....	.....	.....	.....
	1.0000					
For 20 per cent. excess of oxygen, .6748 — .0143 =	.....	.6605	.....	.....	.....	2.1797
Totals	.....	4.0343	2.1787	2.1433	.....	13.3507

To convert the above totals of resultant gases into figures, representing the quantities obtained in the combustion of 1,000 feet of the gas, we multiply each quantity by the weight of 1,000 cubic feet of coal-gas, viz., 32 pounds:

Steam	$2.1787 \times 32 =$	69.7184
Carbonic acid	$2.1433 \times 32 =$	68.5856
Nitrogen	$13.3507 \times 32 =$	427.2224
Total product	$17.6727 \times 32 =$	565.5264

Now, as has been previously shown, one pound of coal-gas will produce 22,968 units of heat; then, 1,000 feet will produce thirty-two times that quantity, or 734,976 units, and to this we will add the heat carried in by 129 pounds oxygen, and 427 pounds nitrogen, at sixty degrees, or 7,920 units, making total heat 742,896 units.

$\frac{742,896}{565.5 \times .2868} = 4580$, or possible degrees of temperature.

$\frac{742,896}{152 + 966} = 664.6$ pounds water evaporated from temperature of 60°.

$\frac{742,896 - 81,092}{152 + 966} = 591$ pounds water evaporated from a temperature of

60°, with products of combustion escaping at a temperature of 500°, Fahr:

COMPOSITION OF WATER GAS.

	Volume.	Weight.
Hydrogen	45.00	5.431
Carbonic oxide	45.00	76.041
Marsh-gas	2.00	1.931
Water-vapor	1.50	1.630
Carbonic acid	4.00	10.622
Nitrogen	2.00	3.380
Oxygen	0.50	0.965
	100.00	100.000

The following table shows quantity of oxygen required for complete combustion, and the quantity of resultant gases, including 20 per cent. excess of air:

Water gas.		Oxygen required.	Resultant gases.		
			Steam.	CO_2.	Nitrog'n.
H	.05431	.43448	.48979	.....	1.43378
CH_4	.01931	.07724	.04444	.05310	.25489
CO	.76041	.43452	.....	1 19493	1.43392
H_2O	.01630	.....	.01630	.....	.....
CO_2	.10622	.....	.....	.10622	.....
N	.03380	.....	.....	.....	.03380
O	.00965	.....	.....	.....	.....
	1.00000				
For 20 per cent. excess of oxygen, .18925 — .00965 =		.17960	.....	.....	.59268
Totals		1.12584	.55053	1.35425	3.74907

Multiplying the resultant gases by 45.6, the weight of 1,000 feet of water-gas, gives us the results of the combustion of that quantity of gas:

Steam	.55053 × 45.6 =	25.104168
Carbonic acid	1.35425 × 45.6 =	61.753800
Nitrogen	3.74907 × 45.6 =	170.957592
Totals	5.65385 × 45.6 =	257.815560

Heat units of water-gas = 322,346, and to this we add the heat of the air, 3174 units, which gives total heat of 325,520 units.

$\frac{325\,520}{257.8 \times 26} = 4850°$ of possible temperature.

$\frac{325.520}{152 + 966}$ 290.1 or pounds of water evaporated from temperature of 60°.

$\frac{325.520 - 32.500}{152 + 966} = 262$ pounds of water evaporated from a temperature of 60°, Fahr., when products of combustion are escaping from furnace at a temperature of 500°, Fahr.

Composition of Producer Gas.

From analysis made at a Pennsylvania steel-works—gas made from anthracite coal, and, therefore, does not contain illuminating gases:

	Volume.	Weight.
Hydrogen	6.00	.458
Marsh-gas	3.00	1.831
Carbonic oxide	23.50	25.095
Water-vapor	1.00	.686
Carbonic acid	1.50	2.517
Nitrogen	65.00	69.413
	100.00	100.000

Producer-gas.		Oxygen required.	Resultant gases.		
			Steam.	CO_2.	Nitrog'n.
H	.00458	.03664	.04122	.....	.12091
CH_4	.01831	.07324	.04122	.05034	.24169
CO	.25095	.14391	.....	.39486	.47490
H_2O	.00686	.....	.00686	.....	.....
CO_2	.02517	.....	.....	.02517	.....
N	.69413	.....	.....	.....	.69413
For 20 per cent. excess of oxygen		.03076	.....	.....	.10151
Totals		.28455	.08930	.47039	1.63314

This gas is not so heavy as the gas made from soft slack coal, and weighs but 77.5 pounds per 1,000 cubic feet:

Steam	.08930 × 77.5 =	6.921
Carbonic acid	.47037 × 77.5 =	36.456
Nitrogen	1.63314 × 77.0 =	126.568
	2.19281 × 77.5 =	169.945

This producer-gas generates 1,850 units per pound, and this multiplied by 77.5 pounds gives us 143,375 units per 1,000 feet of gas; and to this we add the heat carried in by 95 pounds of air, at a temperature of 60°, Fahr., = 1,357 units, making a total heat of 144,732 units.

$\frac{144,732}{170 \times .2474} = 3,441$, or possible degrees of temperature.

$\frac{144,732}{152 + 966} = 129.5$ pounds of water evaporated from temperature of 60°.

$\frac{144,732 - 16,029}{152 + 966} = 115.1$ pounds of water evaporated from a temperature of 60°, Fahr., with waste gases escaping from furnace at a temperature of 500°, Fahr.

From the foregoing calculations it will be seen that the value of the gases for evaporating water from a temperature of 60°, Fahr., when resulting-gases are escaping at 500°, Fahr., and when there is 20 per cent. excess of air introduced with all the gases (and in all cases, ignoring radiation), is, for 1,000 feet, as follows:

Natural gas will evaporate	893	pounds.
Coal gas " "	591	"
Water gas " "	262	"
Producer gas " "	115	"

Uses.

Natural gas, as well as manufactured gas, can be used for almost any purpose for which solid fuel can be used. The reduction of metalliferous ores, especially ores of iron, is perhaps the only exception. For this purpose it fails, probably from no inherent defect or lack of quality, but from the fact that the proper apparatus has not yet been invented by the employment of which gaseous fuel can be used.

In the blast-furnace as now constructed, the ore is kept separated and prevented from forming an agglutinated mass impervious to blast by the solid fuel charcoal, coke, or anthracite coal.

The ore does not escape from or get below (in the normal working of a blast-furnace) the solid fuel until the mineral has been reduced to

the metallic state and until it has become a fluid trickling down through the fuel, accumulating in a molten mass below where the air blast enters the furnace.

Many futile attempts have been made in modern days to work ores direct from the mineral into wrought-iron or steel. In most of these attempts gaseous fuel could have been used, and in some was used with advantage.

The composition of natural gas, however, is such that it can never be used for the reduction of iron ore with the same advantage that it may be used in many other branches of the iron industry. At the temperature of melting iron, and even much below that, the iron will decompose steam, forming an oxide of iron and free hydrogen. This being true, it follows that the full benefit could not be derived from the introduction of free hydrogen into a mass of fluid metal, or where it would come in contact with highly heated and partially reduced ores, or with incandescent carbon used in connection with gas.

For melting steel, for heating and puddling iron, for use in the manufacturing of glass, for raising steam, for warming residences, business houses, and factories, for burning lime, and for almost every purpose for which fuel is ever used, it has been eminently successful.

For all the purposes mentioned it is economical, cleanly and desirable from almost any standpoint. In northwestern Ohio it is extensively used for lime-burning. In fact it is believed that kilns located outside of the gas belt must be driven to a suspension or abandonment of the business, it being impossible to use wood for fuel in competition with gas.

Cooking.

In the cities of Pittsburgh and Allegheny, and in the towns of that vicinity there are thousands of residences heated by gas and in which the cooking is done by the aid of this fuel.

In this direction it is perhaps doing more to cultivate a desire for gaseous fuel than in any of the numerous other uses to which it has been applied. Aside from its great convenience, gas is superior to solid fuel for cooking. There is an erroneous impression prevailing with many who have not had experience in the use of gas for cooking, that food, and especially meats, cooked with this fuel tastes of the gas. This is impossible, unless there be carelessness in its use, and imperfect combustion occurs.

Neither natural nor manufactured gas contains any element or compound that is not contained in coal, but these gases are usually free from some obnoxious compounds found in coal or generated in the combustion of coal, such as phosphoric acid and sulphydric acid.

The waste products of the combustion of gas, however, should not be permitted to escape in the room. A hood placed over and a short distance above the gas stove, and attached to a flue or chimney with a fairly good draft will not only carry off the burnt gases, but also the odors rising from the meats and vegetables that are being cooked.

Gas is an economical fuel with which to cook, for two reasons; first, all expense for fuel will cease the instant the cooking is completed, and second, in the matter of roasting. There is a much smaller percentage of waste in meat roasted in a properly constructed gas stove than occurs in the best stoves using solid fuel. A great number of experiments made a few years age in London by a committee of experts demonstrated that meat roasted by the best gas roasters lost but ten to eleven per cent. of weight, that is, the cooked meat weighed ten to eleven per cent. less than did the raw meat, while with coal heated stoves the loss in meat ranged from twenty to twenty-five per cent. This last item alone would go a long way toward paying the additional cost of gas over coal, if in fact, any additional cost occurs. Natural gas, as it is usually sold, of course, is very much cheaper for cooking purposes than any solid fuel can be.

For domestic heating, the warming of residences, natural gas has no equal, barring possibly the slight element of danger attending its use.

There are devices now in use that automatically turn on and off the gas, so as to maintain the temperature at any desired degree. These devices are so sensitive that a change of one degree in temperature will be sufficient to cause them to turn off or put on more gas, as may be required to maintain an equable temperature and when set to maintain the temperature of a room at 70 degrees Fahr., will prevent the temperature of that room falling below 69 or rising above 70 degrees.

MEASUREMENT OF GAS-WELLS AND OTHER GAS-STREAMS, AND THE PIPING OF NATURAL GAS.

COLUMBUS, O., *June* 10, 1886.

DR. EDWARD ORTON, *State Geologist of Ohio:*

DEAR SIR: I respectfully give below the results of the investigation requested by you, of means most feasible for measuring the discharge of gas-wells.

Sincerely yours,

S. W. ROBINSON.

CHAPTER IX.

MEASUREMENT OF GAS WELLS AND OTHER GAS STREAMS, AND THE PIPING OF NATURAL GAS.

By Prof. S. W. Robinson, Ohio State University.

I. GAS-WELLS.

Some of the recently bored gas-wells in Ohio are discharging gas at too high a rate to be measured conveniently with an ordinary gas anemometer, since the delicacy of the instrument is such that it cannot stand the violence of the current. To use it would require reduction of velocity by increasing the diameter of the stream of flowing gas from the well. This may be done by means of flaring tubes fastened to the well-mouth, which, however, is attended with some cost and trouble, the avoidance of which is desirable. To this end I was invited by the State Geologist, Dr. Edward Orton, to consider the question of gas-well measurement.

The correct measurement of such a gas stream, where the temperature, density and velocity are all unknown, appeared to be a matter of considerable difficulty, even when the anemometer could be applied, because that instrument could make known only one of the unknown quantities, viz., the velocity. The density being still unknown, the weight of gas discharged per minute could not be determined; and as the well-mouth temperature is also still unknown, the density at that temperature cannot be calculated, even if the specific gravity of the gas is known.

Among the various appliances which suggested themselves for application was the Pitot's tube, a shunt, Bunsen's effusion principle for density of shunted gas, and a thermometer enclosed in an open tube, nearly closed at the rear, to be presented as is the Pitot's tube.

On investigation, the Pitot's tube was found to give the value of the product of the density by the square of the velocity. Had it given the density and velocity both to the same exponent in the product, the weight per second could have been found by simply multiplying by the area of the well-mouth; but that not being the case, it was necessary to find the density, or the specific gravity which will serve as well, in the

well-mouth, either directly or calculate it from that of the gas at ordinary conditions. Measuring the velocity by the anemometer would serve, but the use of this instrument was what was to be avoided. By using the shunt of known area of mouth, and storing the gas for a definite time of flow through the shunt, the gas being allowed to gain ordinary conditions, the weight or volume per second for the well could be found from the shunt alone by multiplying the weight or volume per second shunted by the ratio of areas of well-mouth and shunt-mouth.

This shunt device was therefore considered favorably, until some experimental measures were made. But the testing of the devices showed that the shunt could not be relied upon generally, for the reason that the gas sometimes carries oil from the well, which oil would smut the shunt orifice and modify to an unknown degree, the effective area of the shunt-mouth, and correspondingly vitiate the results in such cases. In the Pitot's tube tests the instrument was found to be thoroughly reliable for what it gave, regardless of the heterogeneity of the fluid flowing; and the temperature of the gas could be estimated with some degree of approximation, since the pipes would sometimes freeze the water condensed upon them and sometimes not, at all the wells examined during the testing of the instruments. Also, the Pitot's tube, for convenience of application cannot be excelled, as the completion of an observation is but the work of a moment, regardless of condition of orifice. The encased thermometer was not applied at gas-wells, though it has been well tested in connection with Westinghouse air apparatus.

As all these appliances will doubtless be found useful in the measurement of the streams of gas from gas-wells, and of other gas currents, a description of each and the formulas for reduction of observations will be given.

The Pitot's Tube.

This tube takes its name from the inventor, Pitot, who made it known to the French Academy of Sciences in 1732. (See Morin's "Hydraulics," page 131.) It is shown in all its simplicity and essential principles in fig. 1, in position for determining the velocity of a current of water flowing along its bed with the free surface at *b*. The instrument, as here shown, consists simply of a plain piece of glass tube, L shaped, placed with an open mouth, *a*, presented directly toward the current, while the other end reaches above the surface at *b*. Now, when the water drives against the open end *a*, a pressure results from the impact, which causes the water to rise in the branch *bc*, to a height *h*, which height is to be used as a head by which, in some way, to calculate

the velocity. Pitot concluded that this head was simply that due to the volocity v of the current, so that $v^2 = 2gh$, where g is the acceleration of gravity. This formula is that for falling bodies, and also that for Torricelli's theorem for the velocity of issue of water from an orifice.

According to this, when water is flowing from an opening in the side of a tank, if the mouth of the Pitot's tube, somewhat smaller than the jet, be presented square against the jet, the water would rise in the upright branch of the tube just to the level of the surface of the water in the tank. This simple device, therefore, furnishes us a very handy means for finding the velocity in a stream of water, provided the instrument is reliable for accuracy.

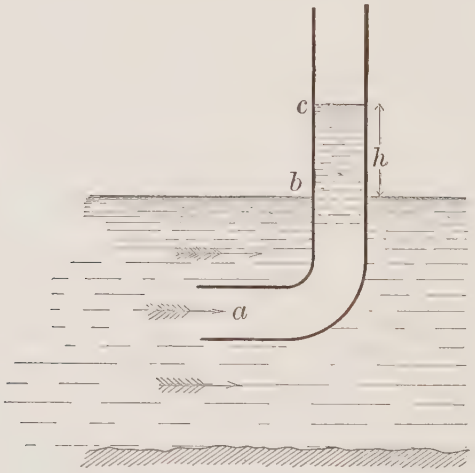


Fig. 1

For over one hundred years after its discovery, this device, so admirable for its simplicity, was regarded more for curiosity than utility, and it was believed not to be reliable for accuracy. (See D'Aubuisson's "Hydraulics" (Bennett's translation), page 158.) But about 1850, M. D'Arcy, an able French hydraulic engineer, seeing in the Pitot's tube the rudiments of a most admirable hydraulic instrument, studied it with a view to reducing it to the most useful form and design for practical purposes, for a complete description of which, see Morin's "Hydraulique," page 133. The main features of this form consist of using two tubes side by side, extending from some distance above water down to desired depth, then turning horizontally toward the current to where one tube terminated in a small mouth of one millimeter diameter presented direct, while the second tube was cut to a long slant and was joined upon the side of the first so as to form a smooth and converging exterior surface. Near the front termination of the second tube and

about half an inch back from the open mouth of the first tube was a small hole laterally. The top ends of the tubes were glass and connected across, so that when water was drawn up by sucking the air partially from the tubes and closing a cock, the columns of water would stand at a height convenient for reading.

The instrument was thoroughly tested, and instead of being a mere toy, was found to be an instrument of precision. Also, as a more surprising fact, instead of requiring a large and varying correction factor, it was found to follow Pitot's originally stated principle exactly, viz., $v^2 = 2gh$, where h is the differenc of level of the tops of the two columns.

From the fact that it has been so little used, it is believed that this Pitot's tube appliance has been regarded as too simple to be reliable, whereas, its simplicity, instead of condemning it, should have commended it so far as to give it more trials than it has had, which, when thus tried, it is certain would gain a high place in the estimation of the investigator.

A further modification in form and design of this instrument was made in 1877, a full description of which was given in Van Nostrand's Magazine, in Vol. XVIII.

About 1873, some interesting experiments were made by the writer on the use of the Pitot's tube for the determination of the velocity and form of jets of air from orifices under a head of two to four inches of water, which experiments, as far as known to me, were the first in the application of Pitot's tube to gases. Orifices of one inch and two inches diameter were employed. The Pitot's tube, in this case, consisted of a glass tube about two feet in length, bent twice at one end for an inverted U water manometer, while the other end was drawn out into a fine point or mouth, of about five-thousandths of an inch diameter. The instrument was mounted on a slide so as to be moved by scale, either across or lengthwise the jet. It is seen that by this arrangement the precise form of the longitudinal section of the jet, and its velocity at any point of any cross-section could be made out. The stream was found to have a *vena contracta* much as in water jets, though shorter, and a velocity which varied from side to side in carrying the instrument across the jet, the maximum being at the middle, and very considerably higher than that at the side.

Most of the particulars respecting the jet are given in fig. 2, for the two-inch orifice AB, beveled to a sharp inner edge. The contracted section is near CD, and the length of the *vena contracta* is about a fourth of the diameter of the orifice, whereas, in water-jets, it is about a half to two thirds. The diameter of the jet is given for every fourth of an inch for the first inch, and then for the half inches. At twelve inches from

the orifice, the jet was four and a quarter inches in diameter. EF is the velocity curve, the velocities varying from 95 to 122 feet per second through the orifice, with the water manometer varying from two to three and six-tenths inches.

The most remarkable thing observed at this time was the fact that when the mouth of the instrument was extended some three or four inches into the tank by reaching the long neck provided on this Pitot's tube in through the orifice of issue of air under experiment, the pressure for which position being, of course, that of the interior, and then drawn slowly outward along near the middle of jet, until the mouth of the Pitot's tube had reached a distance of one or two inches outside the plane of orifice of issue, the pressure indicated by the manometer was all the while precisely the same, the current through the orifice being all the while unobstructed. Here it seems certain that for mouth of tube within the tank the pressure by tube manometer is almost entirely statical, because the current here must be slight, and that at the outside of the plane of orifice the pressure indicated must be dynamic, or due to impact of air against end of tube mouth, and also that between these points there must have been a mixture of static and dynamic pressure. This strikingly illustrates the fact that as the internal pressure of a particle of fluid diminishes, the stored energy increases, and that as the potential energy due to the pressure falls, the actual energy of motion rises, the sum of the two being a constant, for particles of fluid flowing through a frictionless orifice from a higher to a lower pressure. It also proves that the Pitot tube will exactly indicate a pressure or head due to velocity, when the statical pressure is eliminated, as done in the D'Arcy form of instrument. This form is that proper for use intermediate along a pipe or conduit carrying water, compressed air, or gas a considerable distance where there will be a considerable amount of statical pressure in the fluid. The latter will be eliminated in the D'Arcy form of instrument by the lateral orifice, the difference between the pressure there and at the front orifice being the dynamic pressure from which to find the velocity of fluid.

The general application of the Pitot tube to all fluids will involve consideration of variation of density of fluid under flow, so that formulas for invariable and also variable density will be required. For elastic fluids, the density will always vary, though, for many cases, the variation will be so slight that it may be neglected. Thus, at gas-wells, when $h = 4$ inches of water, the absolute pressure of the atmosphere into which the gas flows is about 400 inches, the variation of pressure being only one per cent., while in the Karg well, where the pressure gauge of the Pitot's tube goes up to fifteen pounds per square inch (one atmos-

phere), the density will fall nearly 100 per cent. in expanding from the tube-mouth to the atmosphere.

For low-pressures, the apparatus shown in fig. 3 will serve where A is the well-mouth or other orifice; BB, the Pitot tube; C, a piece of rubber hose; D, a glass tube; E, a second piece of rubber; and F, a second glass tube. Now, filling the part DEF with water from D to F, then it is plain that a pressure is caused at B by impact of gas from the well, it will be transmitted to D, depressing D and raising F, giving a

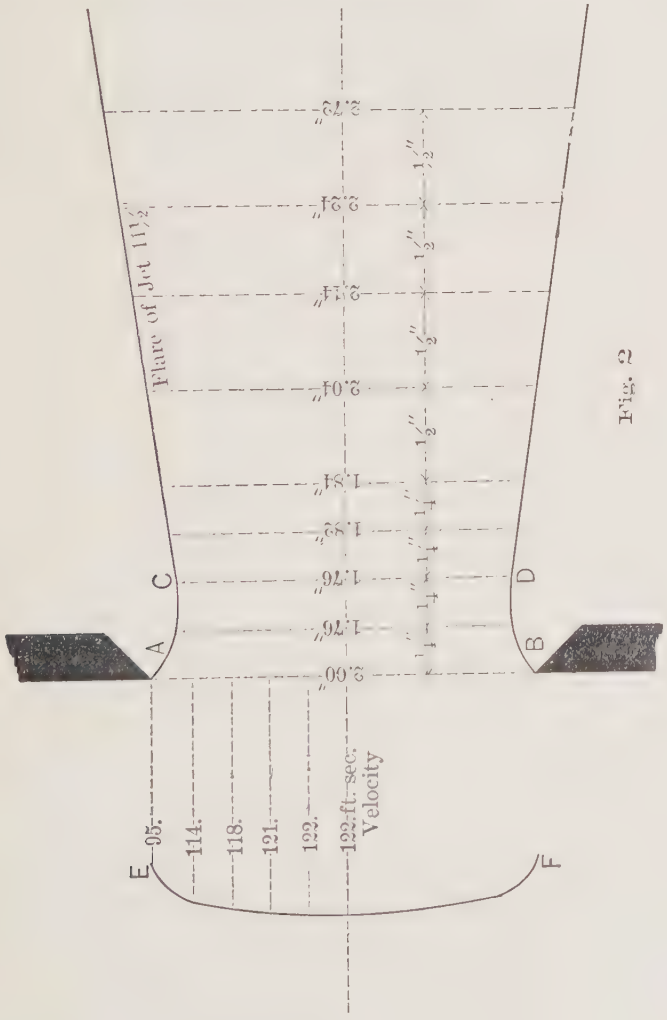


Fig. 3

$$\text{difference of level DF} = h = \frac{v^2}{2g}: \qquad (1)$$

By making E of some three feet length, the glass tubes can be raised, F above D, as required for greater or less values of h. When h exceeds three or four feet, it will be advisable to use a pressure gauge on the end of B, as shown in fig. 4. In use, it is advisable to pass the mouth of B to all portions of the well opening, and thus average for the section.

If it be suspected that there be a residual statical pressure in the gas at the mouth of the tube B, it may be tested and eliminated, if existing by using a double tip of B, with a direct and a lateral opening, one connected to the pressure side D, and the other to the vacuum side F, of the pressure measuring device. But according to all the best authorities on flow of gases through orifices, such as Weisbach, Rankine, Zeuner, etc., the internal residual statical pressure of a jet, on entering the atmosphere, or generally on flowing from a higher to a lower

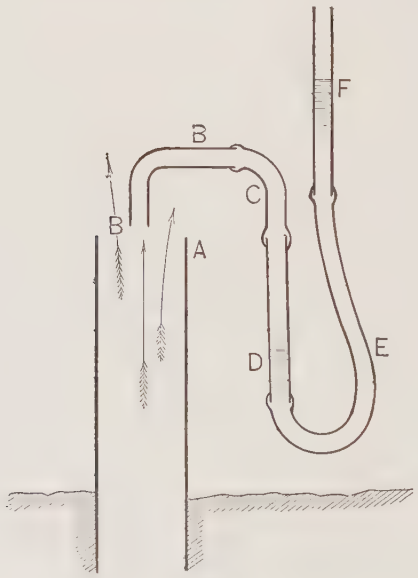


Fig. 3

pressure, becomes the latter as soon as, or very soon after the plane of the orifice is passed. This fact is verified by placing the mouth end of B at right angles to and within the jet, when no appreciable pressure will be indicated.

The theory of the instrument for the case of great fall of pressure in flow of elastic fluids will be reassured, if even support is unnecessary, by citation of experiments recently made in flow of air from a receiver

at twenty to forty pounds per square-inch, through an orifice, to the atmosphere. Air was pumped into a Westinghouse air brake reservoir to about forty pounds, and allowed to escape through a quarter-inch orifice beveled from the outside to the plane of the inside surface, thus securing the conditions of an orifice in a thin partition, or very nearly a theoretical orifice. An accurate pressure gauge, graduated pound by pound, was placed upon the receiver. A second gauge, duplicate of the first, was put on the Pitot tube, the mouth of which was 0.065-inch in diameter. The orifice was opened, and into the air-stream the mouth of the Pitot's tube was placed, and the pressure of the two gauges noted simultaneously as the air escaped, and the pressure run down. The

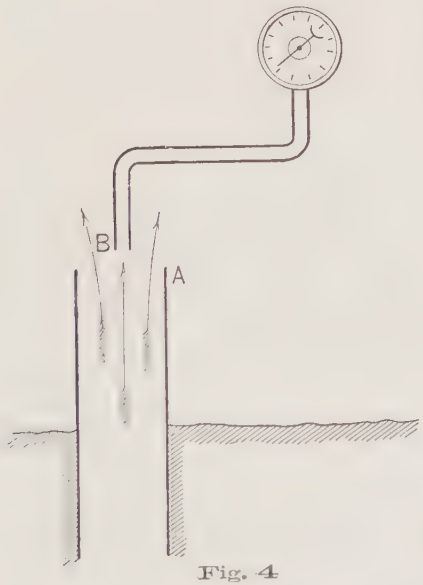


Fig. 4

gauges kept exactly together, as long as the Pitot tube-mouth was fairly within the current and not over one and a half diameters of orifice distant from the orifice.

Three other like experiments were made and noted, the figures for which are given in the following table. The mouth of the Pitot tube, in each case, reached about an inch into the receiver, and then was withdrawn step by step, as the pressures were noted, the note "at orifice," meaning that the tube-mouth was at the plane of orifice, and "⅛" out," meaning one-eighth inch outside of plane of orifice, but always in the jet.

TABLE OF SIMULTANEOUS RECEIVER AND PITOT TUBE PRESSURES.

First experiment.			Second experiment.			Third experiment.		
Receiver.	Tube.		Receiver.	Tube.		Receiver.	Tube.	
30	29½	.....	27½	26½	.....	28	27½	.....
26½	26½	.....	24½	24	.....	25	24½	.....
24	24	.....	21	21	At orifice.	22½	22½	At orifice.
22	22½	At orifice.	20	19½	⅛″ out.	20½	20½	⅛″ out.
20	19½	Out.	17	15½	½″ "	18	16½	$\frac{7}{16}$″ "
18	17½	.....	16½	14	¾″ "	16½	13	1″ "

These figures show that the pressure in the receiver and that in the Pitot tube agree with practical exactness, as the mouth of the Pitot tube is withdrawn from the position extended an inch within until the mouth is over one-eighth inch outside (a diameter by other experiments and probably the same here, viz., one-fourth inch); and that when the tube-mouth is four diameters outside, its pressure is up to three fourths that of the receiver. Besides this, in determinations of tube-pressure at gas-wells, it was found that the same pressure was got whenever the mouth of the tube ranged within a diameter of well-mouth in distance from it.

In the above experiments the jet of air was forced direct and square against the Pitot tube-mouth when outside, so that the cause of the pressure was wholly dynamic, and not at all static; that is, that at points just in front of the orifice, there is no residual statical pressure. Experiments were made to test this point by making a D'Arcy form of double-mouth Pitot tube, one mouth being direct as before, and the other on the side of the tip, as shown in fig. 5, at A and B, respectively. Small holes were drilled back from the mouths A and B, and entirely independent of each other and connected at the rear, one with one standard gauge at C, and the other with another at D, all combined into a portable device.

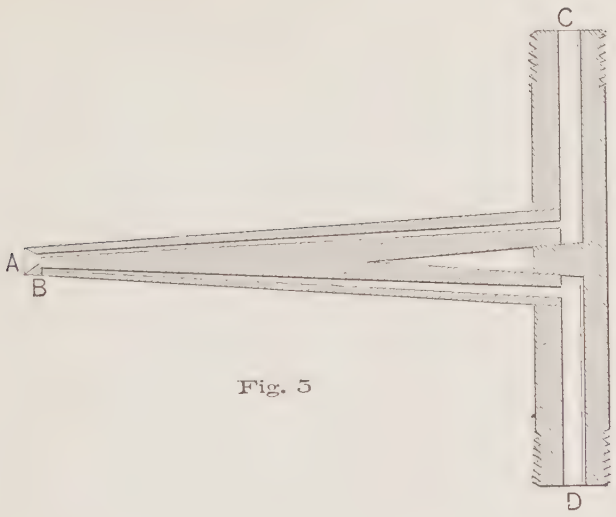


Fig. 5

Now, the mouth A will communicate the pressure due to direct impact, while at B, the moving fluid will tend to move straight by, and will cause no action at B, except for the lateral statical pressure of the jet at the point B, as concluded by D'Arcy for his improved tube for gauging streams of water.

This tip AB, fig. 5, was inserted to some distance through the orifice into the receiver and then withdrawn, step by step, until some distance outside; and the indications by both gauges noted simultaneously at the steps, where the tip was held steady for a few seconds.

When AB is within the receiver, the two gauges should, of course, indicate nearly the same, while, when outside, the gauge for B should stand at zero. Results of test are given in the following table.

In examining this table, consider the third experiment, for instance. When the side-mouth B was a quarter of an inch inside the receiver, the gauge for that mouth indicated 23 pounds per square inch, while the gauge for the direct mouth, A, indicated 22 pounds. When B was at the plane of the orifice its gauge stood at 20, and that for A at 19 pounds. For B, $\frac{1}{16}$-inch outside the plane of the orifice, its gauge stood at 15 pounds, and that for A at 17 pounds. Again, for B, $\frac{1}{8}$-inch outside, its gauge stood at zero, while that for A stood at 16 pounds; the lateral pressure, or statical pressure, of jet vanishing entirely within the space of a sixteenth of an inch, which space lies about at the terminus of the *vena contracta*, or about at CD, fig. 2.

TABLE OF SIMULTANEOUS DIRECT AND SIDE-MOUTH PITOT TUBE PRESSURES, TO TEST FOR STATICAL PRESSURE OF JET.

Distance of side outlet from plane of orifice.	Pressure by gauge connected with mouth.							
	First experiment.		Second experiment.		Third experiment.		Fourth experiment.	
	Direct	Side.	Direct.	Side.	Direct	Side.	Direct.	Side.
Inside, $\frac{3}{8}$ inch	24	25	26	27	.....	.....	.....	.....
" $\frac{1}{4}$ "	22	23	24	25	22	23	.....	.....
" $\frac{1}{8}$ "	20	21	22	23	20	23	21	22
At orifice	17	18	20	19	19	20	20	19
Out, $\frac{1}{16}$-inch	.....	.....	.....	.....	17	15	18	13
" $\frac{1}{8}$ "	14	0	19	1	16	0	16	0
" $\frac{1}{4}$ "	12	0	15	0	14	0	15	0

Hence, the two gauges practically agree within the receiver, and that for B falling from agreement with A, at the plane of the orifice, to zero at the contracted section; at which latter section, therefore, there is no residual statical pressure. In cases where there is no *vena contracta*, as for the cylindrical ajutage, for instance, or the mouth of cylindric pipes, there can be no residual statical pressure at the plane of the exit mouth, the contracted section in this case.

The fall of pressure from 22 to 14 for the direct mouth A of the third experiment, was not due to the withdrawal of the tube from the receiver, nor in any other experiment; but the fall was owing to the exhaustion of the receiver of air on account of the flow; the pump not being able to maintain pressure.

From all the above facts of experiment for high and low-pressures, we are forced to the conclusion that the Pitot tube is a thoroughly reliable instrument for determining the pressure or dynamic head to which the velocity of flow is due, and that the original notions announced by Pitot respecting the relation of velocity and head are rigorously substantiated, not only for flowing water, as he announced, or even other liquids, but for all kinds of fluids, elastic as well as inelastic, except, possibly, for viscous fluids, like molasses or tar.

It appears, then, that in calculating the velocity of flow from a receiver, the pressure to be used for head may just as well be taken from the Pitot tube as from the receiver direct, and the same formula is to be

used for the one as for the other. Hence, where there is no receiver to gauge from, we may proceed with the Pitot tube.

Velocity Under Small Pressures.

To calculate the velocity of flow for fluids where the change of density during flow can be neglected, we employ the formula of Pitot, but for gases the head h must be found on the supposition that h is the depth of the gas from the orifice up to any imaginary free surface, throughout which the density is uniform and the same as at the orifice. Then the pressure, per unit surface upon the orifice, will be—

$$p_1 - p_2 = \delta h \text{ or } h = \frac{p_1 - p_2}{\delta}, \tag{2}$$

where δ is the specific density of the fluid flowing, or the weight per cubic unit. Thus, for air flowing from a receiver where the absolute pressure is p, into a space where the absolute pressure is p_2, the effective pressure will be $p_1 - p_2$, as above. Hence

$$v_2 = 2g \frac{p_1 - p_2}{\delta} \tag{3}$$

a general formula for case of slight variation of δ.

At the mouth of a gas well the pressure of the gas flowing is the atmospheric and its density is

$$\delta = .0807\ Sg \frac{\tau_0}{\tau} \tag{4}$$

where $Sg.$ is the specific gravity of the gas, air being 1, τ_0 the absolute temperature of melting ice, and τ the absolute temperature of the flowing gas. But

$$\frac{\tau_0}{\tau} = \frac{273}{273 + t} \text{ Cent.}^\circ = \frac{493}{461 + t} \text{ Fahr.}^\circ$$

Introducing these into the Pitot formula and taking $2g = 64.3$, we get for units in feet,

$$\begin{aligned} v &= 338.7\left(1 + \frac{t}{546 + t}\right)\sqrt{\frac{p_1 - p_2}{Sg}} \text{ Cent.}^\circ \\ &= 338.7\left(1 + \frac{t - 32}{954 + t}\right)\sqrt{\frac{p_1 - p_2}{Sg}} \text{ Fahr.}^\circ \end{aligned} \tag{5}$$

where t is the temperature of the flowing gas.

Applying this to a gas-well, $p_1 - p_2$ is the effective pressure indicated by the pressure gauge, and taking the temperature at the freezing point and $Sg.$ at 0.6 for an approximation, we have

$$v \text{ approx.} = 437.3\sqrt{p_1 - p_2}. \tag{6}$$

Suppose the pressure gauge on the Pitot tube reads one pound. Then $p_1 - p_2 = \textit{one pound}$ and $v = 437.3$ feet per second.

For small pressures, such that the water manometer is used, as in fig. 2, one pound pressure is equivalent to 27.5 (nearly) inches of water, and by putting h, the head, in inches of water, we have

$$p_1 - p_2 = \frac{h}{27.5},$$

$$v = 64.37\left(1 + \frac{t}{546 + t}\right)\sqrt{\frac{h}{Sg}}\ \text{Cent.}^\circ$$

$$= 64.37\left(1 + \frac{t - 32}{954 + t}\right)\sqrt{\frac{h}{Sg}}\ \text{Fahr.}^\circ \qquad (7)$$

and taking $Sg = 0.6$,

$$v\ \text{approx.} = 83.1\sqrt{h} \qquad (8)$$

Suppose the manometer gives 27.5 inches of water, = 1 pound pressure. Then (8) gives $v = 437.3$ feet per second.

Velocity Under Great Pressures.

When a gas flows from a receiver into a space outside with a relatively large fall of pressure, the formulas for adiabatic flow of gas are to be employed for calculation. The correct formula for this is found in most of our best authorities, viz.:

$$v^2 = \frac{2\,g\,\gamma\,p_2}{(\gamma - 1)\,\delta}\left\{\left(\frac{p_1}{p_2}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right\} \qquad (9)$$

in which, for the present use, p_1 = absolute pressure by Pitot's tube gauge; p_2 = absolute pressure of air = 14.6 pounds per square inch; δ = weight unit vol. of flowing gas at mouth of Pitot tube $= .0807\frac{\tau_0}{\tau}Sg$; τ_0 and τ = absolute temperatures, as before; Sg = specific gravity of flowing gas at mouth of Pitot tube, air = 1; $\gamma = 1.408$; $\frac{\gamma}{\gamma - 1} = 3.451$; $2g = 64.3$; m^2 = value in parenthesis: then, introducing the numerical values and reducing, we obtain:

$$v = 2404\,\frac{m}{\sqrt{Sg}} + \frac{t}{546 + t}\,2404\,\frac{m}{\sqrt{Sg}},\ \text{for Cent.}^\circ;\ \text{and}$$

$$v = 2404\,\frac{m}{\sqrt{Sg}} + \frac{t - 32}{954 + t}\,2404\,\frac{m}{\sqrt{Sg}}\ \text{for Fahr.}^\circ \qquad (10)$$

If the temperature of the flowing gas be taken at that for melting ice and Sg at 0.6, we obtain the approximate formula

$$v\ \text{approx.} = 3103m. \qquad (11)$$

TABLE I.

To Facilitate Calculations of Velocity and Temperature of Flowing Gas, in which $p_1 - p_2$ is the Observed Pressure by Gauge on the Pitot's Tube, and m the Value of the Bracketed Quantity in Equation (9).

$p_1 - p_2$ or observed gauge pressure.	$\frac{p_1}{p_2}$	m.	m^2.
0.5	1.034	.100	.0100
0.75	1.051	.120	.0144
1.0	1.068	.138	.0189
1.5	1.103	.170	.0287
2.0	1.137	.195	.0390
2.5	1.171	.216	.0467
3.0	1.205	.236	.0555
3.5	1.240	.254	.0643
4.0	1.274	.270	.0729
4.5	1.308	.284	.0817
5 0	1.342	.299	.0894
5.5	1.377	.312	.0973
6 0	1.411	.324	.1051
6 5	1.445	.335	.1122
7.0	1.479	.346	.1197
7.5	1.514	.357	.1274
8.	1.548	.368	.1351
9.	1.616	.387	.1498
10.	1.685	.403	.1624
12.	1.822	.436	.1900
14.	1.959	.461	.2126
16.	2.096	.488	.2381
18.	2 233	.512	2621
20.	2.370	.533	.2833
25.	2.712	.578	.3341
30.	3.054	.617	.3807
35.	3.397	.653	.4254
40.	3.740	.683	.4665
45.	4 082	.709	.5027
50.	4.425	.734	.5388
55.	4.767	.757	.5731
60.	5.110	.778	.6053

The bracketed quantity in equation (9) may be put in the form

$$\left\{\left(1 + \frac{p_1 - p_2}{p_2}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right\} = m^2$$

Developing by the binomial theorem, and (9) becomes

$$v^2 = 2g \frac{p_1 - p_2}{\delta} \left[1 - \frac{p_1 - p_2}{2\gamma p_2} + \frac{\gamma + 1}{6\gamma^2} \frac{(p_1 - p_2)}{p_2} - \&c.\right] \qquad (12)$$

The first term of which is the same as (3), and the remaining terms may be regarded as corrections to (3), modifying it as required for the change from constant to varying density under flow. From this it is

seen that for adiabatic flow, the formula for constant density gives values which are too high.

Confirmation of the Formulas.

The shunt has been used to verify results by the Pitot tube in the flow of air and of gas under variable density.

1. For air, the Westinghouse Reservoir was charged with compressed air to seventeen pounds per square-inch, and the one-fourth inch orifice opened for discharge, while the shunt-mouth was introduced into the issuing jet for eight seconds, and the pressure noted for every two seconds as follows:

Verifying Experiment with Shunt.

Seconds.	Receiver pressure.	Means by pairs.	Calculated velocities.
0	17		
		16.50	1,115
2	16		
		15.75	1,083
4	15½		
		15.25	1,070
6	15		
		14.75	1,056
8	14½		

Mean velocity, feet per second, calculated 1,081
Velocity by the shunt, feet per second, calculated 1,006

The shunt orifice was 0.065 inch in diameter, and the shunted air was 40.08 cubic inches per second. The shunt orifice (explained later) was one of no resistance, and the gas-bag and connecting pipes offered no appreciable resistance. The shunt orifice, however, could never have a greater effective area than that measured, while slight traces of dust would make it less. The possibility of some lingering dust, and the resistance of connections would account for part of the difference of velocities 1,081 and 1,006 observed.

It is to be observed that the shunt is theoretically a positive measurer of velocity, so that the 1,006 feet may be regarded as positively not far from, though probably less than the actual velocity.

Hence the 1,083 feet velocity, given by the Pitot tube calculation, is to be regarded as a fairly reliable result.

2. At a gas-well the Pitot tube and shunt were both applied in quick succession, each several times, with mean results as follows:

Velocity by tube = 1,178 feet per second.
" shunt = 1,111 " "

The shunt-mouth was cleaned out each time applied, to clear it of possible obstructions, though no evidence was found of interfering matter.

3. At a second gas-well the results were as follows:

Velocity by tube = 1,016 feet per second.
" shunt = 876 " "

This well carried traces of oil along with the gas, so that the hand placed in the jet in a few seconds would be smutted with oil. Hence, there can be no doubt but that the oil deposit in the shunt-mouth, noticed at the time, had a very appreciable effect in cutting short the flow by shunt. This discrepancy of results is therefore expected, and that fact here serves for verification.

Pitot Tube Mouth.

By regarding the pressure obtained by this instrument as due to the impact against the open mouth, it is easily seen that the amount of action is proportional to the area of mouth, so that this area is independent of the observed pressure. In the experiments, the largest mouth was $\frac{7}{16}$ inch, another was $\frac{1}{4}$ inch, and the smallest was 0.065 inch in diameter, giving the following results at the Karg gas-well where all were tried:

Test for Size of Tube-Mouth.

	Mouth 0.065-inch diameter.	Mouth $\frac{1}{4}$-inch diameter.	Mouth $\frac{7}{16}$-inch diameter.
1, side	12	13.5	—
2	14	15	14.5
3, center	15.5	15	15
4	14	14.5	10
5, side	9	9.5	—

Each figure in the table is the mean of two observations. The observed pressures agree well for the different sizes, and indicate absolute independence of size of tube-mouth.

The small mouth is the one used for the shunt. All were formed sharp, or very nearly so, at the front end of tube around the mouth, and no experiments were made with a dull mouth-rim.

The Shunt.

A shunt properly constructed for this purpose should offer no resistance to the movement of the fluid, so that when a particle of shunted gas has just fairly entered the shunt-mouth, its velocity should be the same as that of the stream around it.

The connecting tube, for as great a portion of length as possible between mouth and collecting bag, should be large, and yet it should be gradually enlarged from the point or mouth in order not to present a blunt end for impact of gas, and thus modify the flow into its mouth.

To thus secure a tapering tip, and at the same time an orifice of no resistance, the device of making the inside with a gradual flare for an inch or two was resorted to, and such a flare that the resulting loss of velocity and consequent loss of energy of motion in the passage would just compensate for the frictional resistance to be overcome in this small part of the passage. After thus getting a suitable distance from the mouth, a sudden enlargement was made to such size as to reduce the remainder of the connecting pipes to practically no resistance.

If v = velocity of fluid at the mouth end, and v' that at the larger end where the sudden enlargement occurs, then the loss of energy of motion between the points will be

$$\tfrac{1}{2}\,\mathrm{M}\,(v^2 - v'^2)$$

where $\mathrm{M} = \dfrac{\delta a v}{g}$ per second.

δ being the density and a the area of passage-way.

The work overcome in frictional resistance per second will be the force into the space.

$$\mathrm{F}v = f\,\delta\,\pi\,dl\,\frac{v^2}{2g}\,v = \frac{\delta a v}{2g}\,(v^2 - v'^2) \qquad (12)$$

Where f is the coefficient of fluid friction, d the diameter of the narrow part, g the passage, and l its length. Observing that av = the volume per second $= \dfrac{\pi d^2 v}{4}$, and constant for at least an infinitesimal length, we reduce the above to

$$2a\,\frac{v - v'}{v} = \pi d f l,$$

or

$$l = \frac{d' - d}{f} \qquad (13)$$

The same result would have been obtained had the equations been worked out for an infinitesimal length and variable density, and then integrated.

The final result shows that the difference of diameter at the opposite ends of the flaring smaller part of the passage is independent of the total diameter.

The value of f is about 0.006. Now, making $d' - d = \frac{1}{100}$ of an inch, then $l = 1.67$ inches. These are the figures, according to which the shunt tip experimented with, was made. The diameter at the mouth of the tip was 0,065 inches, and at the 1.67 inches distance from the tip the passage was 0.075 inches, where it quickly enlarged to $\frac{1}{4}$ inch, the size for $2\frac{1}{2}$ inches; beyond which, for about 18 inches, it was about $\frac{3}{8}$ inch, where the light rubber bag was attached for catching the shunted-gas. This bag was made especially for the purpose, of very thin "dental rubber."

When collected, the gas was measured by running it through an aspirator. When thus measured its temperature should be noted.

On account of the passage way in the shunt being formed as one of no resistance, the gas collected per second is regarded as having flown through the shunt-mouth at the same rate that it did outside the mouth, or with the normal velocity of the gas at the well-mouth.

Quantity of Gas Discharged.

The quantity of discharge should be estimated at some standard temperature at which the gas is supposed to stand as if retained collected in a gas-holder, say 50° Fahr. But while the gas is flowing, its temperature will almost always be much lower, on account of the expansion which accompanies the flow. For instance, in the shunt verifying experiment of the air issuing from the receiver at initial seventeen pounds apparent pressure, the density of the stream of air just outside the plane of the orifice was 0.0937, instead of 0.0749 of the surrounding air into which the receiver was discharged, and the volume ac calculated by using the velocity $v = 1083$ would require to be increased about 25 per cent. to obtain the volume of the discharged air on the supposition of being collected and retained in a gas holder at atmospheric pressure, and temperature of 60° Fahr.

The temperature of the air in the same jet from the receiver was about 38° below zero Fahr., which low temperature is to account for the density in the jet.

Taking V for the volume discharged per second, then

$$V = Av\frac{\tau_2}{\tau},$$

where A = area of the stream of gas being measured, as for instance that at the gas-well mouth, or of the well mouth itself, τ, the absolute

temperature of the gas when stored, and τ that of the gas in the stream. But

$$\frac{\tau_2}{\tau} = \frac{273 + t_2}{273 + t} = 1 + \frac{t_2 - t}{273 + t} \text{ Cent.}^\circ$$

$$= 1 + \frac{t_2 - t}{461 + t} \text{ Fahr.}^\circ \qquad (15)$$

Hence,

$$V = Av + \frac{t_2 - t}{273 + t} \text{ Cent.}^\circ$$

$$= Av + Av\frac{t_2 - t}{461 + t} \text{ Fahr.}^\circ \qquad (16)$$

The volume discharged per day of twenty four hours for dimensions in feet will be

$$\text{Vol. per day} = 86400\ V. \qquad (17)$$

The Encased Thermometer; or Temperature of Stream.

In the impact of the gas against the open end of a tube, it is just as true, from theoretical grounds, at least, that the temperature will be restored as well as the pressure. That is, referring to the case of the air issuing from the receiver through the orifice, the pressure in the Pitot's tube by impact, has been shown to be up just to that in the receiver. Consequently, the air was compressed back to its original conditions as to temperature and volume very nearly, since the time for acquiring heat by a particle in the act of passing out against the tube-mouth could not much exceed the fifty-thousandth part of a second. The same is true of the density.

About a dozen experiments were made to test the question as to restoration of temperature in the cup-mouth by means of an encased thermometer arrangement shown in fig. 6. A glass tube, BC, about $\frac{3}{4}$ inch diameter was drawn down at A to about $\frac{1}{8}$ inch diameter, for the mouth to present to the $\frac{1}{4}$-orifice, O, in the Westinghouse apparatus. Inside of AC is shown the encased thermometer supported in the center of the tube, and with its bulb B, as near as practicable to A. In the plug at C is a small hole to allow a current to flow past the thermometer, so that the air in AC will not have time to be modified in temperature after being compressed at A, before it surrounds the thermometer bulb at B for determination of temperature.

There was no thermometer in the receiver to show its temperature. In experimenting, the pressure would fall, in each experiment, from between thirty and forty pounds per square inch to about eight or ten, owing to which the temperature would, of course, fall in the receiver

But, at the same time, air was being pumped in as fast as the pump would work. Under these conditions, it is difficult to tell what the temperature in the receiver at any time was, but as the room was at about 25° C., it is probable that the interior of the receiver ranged from 15° to 20° C.

Exposing the naked thermometer bulb to the jet, while pressure fell from thirty-five to ten pounds, the mercury fell to from three to six degrees below zero C.; but the real temperature of the jet must have been very much lower, from the fact that ice would form on the bulb and not melt, nor even become moist for several minutes after removal of thermometer from jet and exposure to the air of the room, thus proving a great fall of temperature in the act of expansion at the orifice O. The actual temperature of jet could not be expected to be indicated by a naked thermometer in this way, for the reason that the impact of air upon the thermometer bulb, and friction of the flowing air passing it, would give such a tendency to elevation of temperature as to utterly defeat the effort to determine definite knowledge as to the actual temperature of the jet by means of a naked thermometer.

But in presenting the mouth of the *encased* thermometer to the jet, the mercury would stand very nearly steady at about 16° to 22° C., sometimes not falling a single degree. As this temperature was not far from that within the receiver, together with the fact that the naked thermometer would fall from 20° to 25° lower and yet not reach the limit it appears that the encased thermometer is to be relied upon for indicating the temperature in the receiver.

Hence, from all the facts of experiment, and considerations above noted, we are prepared to state the following more general principle; for non-viscous, elastic or non-elastic fluids, viz.:

When any fluid flows from a higher to lower pressure through a frictionless passage, the portion caught direct in a cup mouth will be restored to its original conditions as to pressure, temperature and density.

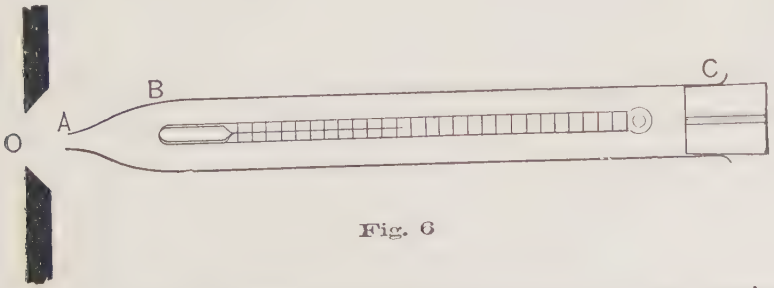


Fig. 6

By using a tube of some non-conducting material, like pasteboard, or *papier maché*, for the casing, fig. 6, extending from A to some distance

past the thermometer bulb, and then glass, better results would doubtless be obtained than for all glass, though glass would be much better than metal.

The temperature of the encased thermometer, as well as the pressure by the Pitot tube, for any stream of gas observed, should be regarded as that of the *equivalent receiver*, that is, a receiver from which the same gas would flow to produce the same jet as that observed for which the temperature and pressure would be that of the encased thermometer and Pitot tube.

This fact is to be taken advantage of for securing the temperature of the flowing jet by calculation from the temperature, as observed from a thermometer placed in the non-conductor tube.

Then the temperature of the stream of gas can be calculated from the well-known relation for adiabatic expansion,

$$\left(\frac{p_1}{p_2}\right)^{\frac{\gamma-1}{\gamma}} = 1 + m^2 = \frac{\tau_1}{\tau} = 1 + \frac{t_1 - t}{273 + t} \text{ Cent.}^\circ$$

$$\text{whence } t = \frac{t_1 - 273m^2}{1 + m^2} \text{ Cent.}^\circ = \frac{t_1 - 461m^2}{1 + m^2} \text{ Fahr.}^\circ$$

where t is the temperature observed from the encased thermometer, m the value found from the table given above, and t the temperature of the stream. When the result for t comes out negative, it is to be read "below zero."

This value of t is to be used in (5), (7) or (10).

Density, or Specific Gravity.

As the formulas for calculating the velocity of flow contain the specific gravity of the gas, some convenient way of finding it is desirable. Where the analysis of the gas in question is not known, Bunsen's Effusion Principle, as already stated, may be applied. A simple way of doing this is to draw a $\frac{3}{8}$-inch glass tube down blunt to a fine orifice, put this into a cork, orifice up, and the cork into a bottle with the bottom knocked out. Then fill the bottle with water, set it into a common plate filled with water. Now, let the water flow out over the edge of the plate and draw air in through the effusion orifice at the top of the tube in the cork and note the time. Then fill the bottle again, and similarly allow the gas in question to flow through the effusion orifice and empty the bottle, noting the time of flow. Then Bunsen's principle makes the densities proportional to the squares of the times, and the specific gravity equal to the ratio of the squares of the times.

A mark may be placed on the neck and near the bottom of the

bottle to start and stop at; and a piece of rubber hose may be stuck upon the effusion-tube and gripped to prevent flow till ready.

The gas may be caught from the gas well by a shunt in a light bag for the effusion-tube to draw from in observing for time of effusion of gas, care being taken to get all air from the connections.

Applications.

Primarily in this investigation, the object was to measure gas-wells, but the appliances are applicable to other streams or currents of gas, even where the fluid is of indefinite extent, as in high winds. Several instances are known of failures of wind anemometers at the critical time of a most valuable record, because of delicacy, complexity, etc., of instrument. In the Pitot tube, we find an instrument of the greatest possible simplicity and stability, one not having a single moving part exposed to the wind.

Thus, to find a reliable wind velocity or pressure of the tornado, put up on strong iron frame-work several Pitot tube points, radiating in different directions, including up and down, each with double mouth, one direct and one lateral, connected properly with a gauge as above explained, with a maximum indicator. This contrivance could be left to stand by itself year after year, observed or not. Finally, the maximum wind-pressure, with direction, could be read off. These could be located at various points about the country, any one of which struck by a cyclone could make known the various interesting facts so much desired as to pressure, velocity, variety of direction, lifting power, etc.

A double mouth tube placed inside a conducting pipe would show by gauge located at any convenient situation, the velocity in the pipe.

Precautions to be Observed in Estimating the Service Capacity of Gas-Wells.

When a gas-well is allowed to flow freely through a widely opened mouth, its discharge will be greatly in excess of that which would be obtained if the opening for discharge were stopped down to a smaller mouth for discharge. Thus suppose a well discharging through a 4 inch mouth, and the pressure were observed by a pressure-gauge attached to the well-pipe just below the mouth, to be twenty pounds per square-inch. Now, if the opening be reduced to 2-inch diameter, the pressure, by gauge, will rise to some point higher than the previous twenty pounds, or say, to perhaps 100 pounds per square-inch.

In this second case the cubic feet discharged per hour must be less than in the former case, from the simple fact that the resistance to dis-

charge is greater. This is seen to be true by extending the reasoning to smaller and still smaller openings, until finally it is $\frac{1}{2}$-inch, $\frac{1}{3}$-inch, or were entirely stopped, in which reduction of opening the pressure rises higher and higher, until finally the full statical pressure of 500 to 750 pounds of the well is reached.

The rise of pressure, with constriction of opening, will not, as is thus seen, fully compensate for the reduction of opening.

The total resistance to discharge of a well, discharging into free air, consists first, of the resistance of the orifice mouth; second, of the resistance to fluid friction of gas flowing along the well-tubing from bottom to mouth, and third, of the resistance offered to the gas along the strata of the earth from the source of gas to the well-hole.

To determine the value of a gas-well for service, its discharge should be determined for several sizes of opening of discharge-mouth, and the corresponding pressures observed by the gauge on the well below the mouth. Then for future use a curve may be plotted, giving relation of pressures and quantities discharged, when a table of cubic feet per day of discharge may be made out for all the pressures included in the range observed. In this table there would appear in one column the pressure by gauge on well, and in the adjacent column the cubic feet per day supplied by the well at the several stated pressures. These quantities of well-discharge will diminish as the pressures increase.

When the particulars of the well are all known as to size and length of pipe in well, and a single observation for discharge with full data, the quantities discharged by well at different pressures may be made out approximately and tabulated, but the better way is by observing the discharge at the several pressures as above suggested.

The table here suggested for service capacity cannot be made out as a single table applicable to *all* wells, but each well will require its own table peculiar to itself, though this can be readily made out from observations with three sizes of mouth, and better still with more than three.

Formulas and Tables to Facilitate Calculation of Quantities of Gas Discharged by Gas-Wells.

For most cases of practice the preceding formulas may be partly reduced as follows:

Putting the bracketed quantity equal m^2, as found in Table I, and other quantities thus—

$$2g = 64.3 \text{ feet per second.}$$
$$\gamma = 1.408.$$

$$\frac{\gamma}{\gamma - 1} = 3{,}451.$$

$p_2 =$ 14.6 pounds per square-inch.

$\delta =$ weight per cubic feet $= .0807 \frac{\tau_0}{\tau} Sg.$

$\tau_0 =$ absolute temperature melting ice.

$\tau =$ " " of flowing gas.

$\tau_2 =$ " "temperature of storage," or of gas as if stored in a gas holder at the ordinary temperature t_2.

Then we obtain

$$v = 2404m \sqrt{\frac{\tau}{\tau_0 Sg}} \tag{19}$$

and if $Sg = 0.6$

$$v = 3103m \sqrt{\frac{\tau}{\tau_0}} \tag{20}$$

and if $\tau = \tau_0$ we obtain the same as (11)

$$v = 3103m \tag{11}$$

where $v =$ velocity of gas at gas-well mouth.

Then the volume in cubic feet per day discharged by gas-well will be (d being diameter of orifice or well-mouth in inches)

$$\text{V. day} = 86{,}400 \times 3103m \frac{\pi d^2}{4 \times 144} \tag{21}$$

$$\text{V. day} = 1{,}462{,}250m\, d^2 \tag{22}$$

This formula is correct for a specific gravity of gas of 0.6, a temperature of flowing gas of 32° Fahr., and a "temperature of storage" of 32° Fahr.

From this formula (22), Table II was made out.

This so called "temperature of storage" is the temperature that the measured gas is assumed to have if the measured gas were stored in a gas holder at the temperature considered. Thus, suppose that a gas-well discharged its gas into a great gas holder for one day, and that this gas, while in the gas-holder, were measured in cubic feet when the temperature of it was at 50° F. Then 50° is the temperature of storage." But it is not necessary to actually store the gas thus, for the formulas and tables give the quantity discharged by the well, so that the gas can be measured and dealt out to customers without storage, but under the same measurement as if stored.

TABLE II.

CUBIC FEET OF GAS RECKONED AT 32° F., DISCHARGED BY WELL PER DAY OF 24 HOURS OF CONTINUOUS FLOW, BY PITOT TUBE MEASUREMENT; THE SPECIFIC GRAVITY OF THE GAS BEING HERE TAKEN AT 0.6, (AIR = 1.): AND THE TEMPERATURE OF THE FLOWING GAS AT WELL-MOUTH BEING TAKEN AT 32° F.

CUBIC FEET PER DAY RECKONED AT 32° F., GIVEN BY THIS TABLE MAY BE REGARDED AS A QUANTITY OF GAS IN A GAS HOLDER AT THE TEMPERATURE OF 32° F., OR THE "TEMPERATURE OF STORAGE." FOR OTHER TEMPERATURE OF STORAGE, OR FOR OTHER TEMPERATURE OF FLOWING GAS, OR FOR OTHER SPECIFIC GRAVITY THAN 0.6, CORRECT THE CUBIC FEET OF GAS OBTAINED FROM THIS TABLE BY AID OF TABLE III OR TABLE IV. SEE EXAMPLES..

Observed pressure by water-gauge, as in fig. 3.	Observed pressure by pressure-gauge, as in fig. 4.	Diameter of orifice, or of well-mouth where observed as in figs. 3 or 4; in inches.										
		d_2=1 in.	d = 1½	d = 2.	d = 2½.	d = 3.	d = 3½.	d = 4.	d = 4½.	d = 5.	d = 5⅝.	d = 6 in.
Inch's	Lbs. per sq. in.											
.1	.0036	12,390	27,880	49,556	77,440	111,510	151,780	198,220	250,890	309,750	392 000	446,040
.2	.0073	17,560	39,510	70,260	109,750	158 040	2 5,110	281.040	355,590	439 030	555,910	632,160
.3	.0109	21,480	48,330	85,940	134 250	193 320	263,130	343,760	434 970	537,000	679 630	773,280
.5	.0182	27,720	62,370	110,880	173,250	249,480	339.570	443 520	561,330	693,000	877,080	997,920
.7	.0254	32,840	73,840	131,260	205 100	295,380	402 000	525,050	664,610	820,400	1,038 500	1,181,520
1.0	.0364	39.210	88.230	156 830	245,100	352 890	480,400	627,310	794,030	980,400	1,240,700	1,411,600
1.5	.0545	48,030	108,070	192,120	300,200	432,270	583,400	768 480	972,600	1,200,800	1,517,900	1,729,100
2.0	.0727	55,340	124,520	221,360	345,900	498,060	677,960	885 440	1,120,600	1,383,600	1,751,000	1,992,200
3.0	.109	67 910	152.800	271,630	424 500	611,190	832,020	1,086,510	1.375,200	1,698 000	2,148,800	2,444,800
4 0	.145	78.410	176.420	313,660	490,100	705,690	960,600	1,254,620	1,587.800	1.960,400	2.480,900	2.822,800
5.0	.182	87,670	197,260	350,670	548.400	789,030	1,074 860	1,402,670	1,775 310	2,193,600	2,733,900	3,156,100
7.0	.254	103,500	232.880	414 000	646 900	931,500	1,267,900	1.656,000	2,095,900	2 587,600	3,274,800	3.726,000
10.0	.3636	123,000	276,750	492,000	768,800	1,107,000	1,506,750	1,968.000	2,49 ,800	3,075,000	3,890,9 0	4,428,000
13.75	.50	146,220	328,990	584,880	913,880	1,316,000	1,791,200	2 339 500	2,760,900	3,655,500	4,626,500	5.864,000
20.62	.75	175,350	394,540	701,400	1,096,000	1,578,150	2,148,160	2,805,600	3,550,900	4,384,000	5,548,200	6,312,600

27.5	1.00	201,800	454,010	807,200	1,261,200	1,816,950	2,471,900	3,228,500	4,086,100	5,044,600	6,384,600	7,264,200
41.25	1.5	247,840	557,650	991,370	1 549,000	2,231,000	3,036,000	3,965,000	5.019,000	6,196,000	7 842,000	8,922,000
55.0	2.0	285,130	641,540	1,140,500	1,782,000	2.568,260	3,493,000	4,562,000	5,774,000	7,128,000	8,921,000	10,265,000
.....	2.5	316,500	712,130	1,266,000	1,978,000	2,848,500	3,877,000	5,064,000	6,409,000	7,913,000	10,014,000	11,394,000
.....	3.0	344,350	774,780	1,377,400	2,152,000	3,099,100	4,218,000	5,510,000	6,973,000	8,609,000	10,895,000	12,397,000
.....	3.5	370,000	832,500	1,480,000	2,313,000	3,330,000	4.532,500	5,920,000	7,493,000	9,250,000	11,707,000	13,320,000
.....	4 0	393,000	884,250	1,572,000	2,456,000	3,537,000	4,814,200	6,288,000	7,958,000	9,825,000	12,435,000	14,148,000
.....	4 5	415,270	934,350	1,661,100	2 595,000	3,737,400	5,087,000	6,644,000	8,409,000	10,382,000	13,139,000	14,950,000
.....	5.0	436,200	981,450	1,744 800	2,726,000	3,925,800	5,343,000	6,979,000	8,833 000	10,905,000	13,802,000	15,703,000
.....	5.5	456,200	1,026 500	1,824,800	2,851,300	4,105,900	5,589,000	7,299,000	9,238,000	11,405,000	14.435,000	16,423,000
.....	6.0	473,750	1,065,900	1,895,000	2,961,000	4,264,000	5,803,000	7,580,000	9,593,000	11,844,000	14,990 000	17.055,000
.....	6 5	489.840	1,102,100	1,959,400	3,062,000	4,409,000	6,001,000	7.837.000	9,919,000	12,246,000	15,499,000	17,634,000
.....	7.0	505 920	1,138,300	2,023,700	3,162,000	4,553,300	6,198,000	8.095,000	10,245,000	12,648,000	16,008,000	18,213,000
.....	7.5	522,010	1,174,500	2,088,000	3,263,000	4.698,000	6,395,000	8,353 000	10,571,000	13,050,000	16,517,000	18,792,000
.....	8.0	538,500	1,211,600	2,154,000	3,366 000	4,846,000	6,597,000	8,616,000	10,905,000	13,462,000	17,038 000	19,386,000
.....	9.0	565,970	1,273,200	2,263,000	3,537,000	5 093,000	6 932,000	9,054,000	11,459,000	14,147,000	17,905,000	20,371,000
.....	10.0	589,270	1.325,900	2,357,100	3,683 000	5 303,000	7,219,000	9.428,000	11,933,000	14,372,000	18,645 000	21,214,000
.. .	12.0	633,340	1.425,000	2,533,300	3,958,000	5,700,000	7,758,000	10,133,000	12,825,000	15,833,000	20,040,000	22,800.000
.....	14.0	675,000	1,518,800	2,700,000	4,219,000	6,075,000	8,269,000	10,800,000	13,669,000	16,875 000	21,357,000	24,300,000
.....	16.0	713,550	1,605,500	2,854,200	4,459,700	6,422,000	8,741,000	11,415,000	14,449,000	17,839,000	22,577,000	25,688,000
.....	18.0	748,650	1,684,500	2,994,600	4,679,000	6,738,000	9,151,000	11,978,000	15,163,000	18,716,000	23,977,000	26 951,000
.....	20.0	779 350	1,753,500	3.117.400	4,871,000	7,014 000	9,545,000	12.470,000	15,782,000	19,484,000	24,659,000	28,057,000
.....	25.0	845,150	1 901,600	3.381,000	5,282,000	7,606,000	10,353,000	13 522,000	17,114,000	21,129,000	26.741,000	30,425,000
.....	30.0	902.180	2 029,900	3,609,000	5,639,000	8.120,000	11,054,000	14.435,000	18,269,000	22,555,000	28,894,000	32,478,000
.....	35.0	954.820	2 148,300	3.819,000	5,968,000	8,593,000	11,697,000	15,277,000	19,335,000	23,870,000	30,211,000	34,373,000
... ..	40.0	993,630	2,247,000	3,995,000	6,242,000	8,988,000	12,234,000	15,979,000	20,223,000	24,967,000	31,599,000	35,952 000
.....	45.0	1·036,700	2 332,600	4.147,000	6.479,000	9,330,000	12.700,000	16 587,000	20,993,000	25,918,000	32,802,000	37,321,000
.....	50 0	1·072,000	2,412 000	4,288 000	6,700,000	9,648,000	13,132.000	17,152.000	21,708,000	26,800,000	33,919,000	38,592,000
.....	55 0	1,106.880	2 495 000	4.428 000	6.918.000	9.962,000	13,539,000	17,710.000	22,454,000	27,672 000	35,023,000	39,848,000
.....	60.0	1,137,600	2,559,600	4,550 000	7,110,000	10,238.000	13,935,000	18,101,000	23,036,000	28,440,000	36,000,000	40,953,000

As table II is only for a specific gravity 0.6, a temperature of storage of 32°, and a temperature of flowing gas 32°, the table will give correct results only for these data. To meet the requirements for other observed data, without making out a great table for each density and temperature, the plan of correction tables is resorted to. Tables III and IV serve to correct both for specific gravities and temperatures other than those of table II, III being for the same temperature of storage as II, while IV is for a temperature of storage of 50°F., this being regarded as a fair mean temperature of a gas-holder for the year, and for the latitude of Ohio and Pennsylvania.

The general formula partly reduced becomes

$$\text{V. day} = 1{,}462{,}250.\ \tau_2 \sqrt{\frac{Sg_1}{\tau\ \tau_0\ Sg}} \qquad (23)$$

where τ_2 = absolute "temperature of storage."

$= 461.2 + t_2$ Fahr.

τ = absolute temperature of flowing gas.

$= 461.2 + t$ Fahr.

τ_0 = absolute temperature melting ice = 493.2°.

Sg_1 = the specific g avity, 0.6.

Sg = " " observed.

For Table III the absolute temperature, τ_2, is 493 2°, while for Table IV it is 511 2° Fahr., or for ordinary temperatures of 32° and 50° Fahr., respectively.

The corrections in these tables are the differences between the formulas (23) and (22).

TABLE III.

For Temperature of Storage of 32° F. Correction Multipliers to correct the Cubic Feet per Day, Obtained from Table II for other Specific Gravity than 0.6, and other Temperature of Flowing Gas than 32° F.

To use the tabular quantities obtained from this table, multiply them by the cubic ft. per day obtained from Table II, and add or subtract the product. Thus correct 15,400,000 cubic ft. per day from Table II, to a specific gravity of 0 5, and a temperature of flowing gas of 40° F. For this we obtain from this table the multiplier 0.085, and hence the corrected cubic ft. per day is 15,400,000, plus 15,400,000×085=15,400,-

000, plus 1,309,000 - 16,709,000 cubic ft. per day for a specific gravity of 0.5 and 40° temperature of flowing gas at well-mouth.

Or to correct to a specific gravity of 0.8 and temperature of flowing gas of 50° F. This Table gives the multiplier 0.149, and hence the corrected quantity of gas is 15,400,000, less 15,400,000 × .149 = 15,400,000, less 2,294,600 = 13,105,450 cubic ft. per day at the specific gravity 0.8 and 50° F. temperature of flowing gas.

Sp. Gr. gas. Air=1.	Temperature of flowing gas for point observed at well mouth.								
	25°	30°	35°	40°	45°	50°	55°	60°	
.40	.234	.227	.221	.215	.209	.203	.197	.191	Add for quantities above line.
.45	.163	.157	.151	.145	.140	.134	.129	.123	
.50	.103	.097	.092	.085	.081	.076	.071	.066	
.55	.053	.047	.042	.037	.032	.027	.022	.017	
.60	.007	.002	.003	.008	.013	.018	.023	.027	Subtract for quantities below line.
.65	.032	.037	.041	.046	.051	.056	.060	.065	
.70	.068	.073	.077	.081	.086	.091	.095	.099	
.75	.099	.104	.108	.113	.117	.122	.126	.130	
.80	.128	.134	.140	.143	.145	.149	.153	.158	
.90	.178	.184	.189	.192	.194	.198	.202	.206	
1.00	.220	.225	.230	.233	.235	.239	.243	.247	

TABLE IV.

For Temperature of Storage of 50° F., Correction Multipliers to use the same as those of Table III.

Sp. Gr. gas. Air=1.	Temperature of flowing gas for point observed at well mouth.								
	25°	30°	35°	40°	45°	50°	55°	60°	
.40	.278	.272	.266	.259	.253	.247	.240	.234	Add for quantities above line.
.45	.206	.200	.194	.188	.182	.176	.170	.164	
.50	.143	.137	.132	.126	.121	.115	.110	.104	
.55	.091	.085	.080	.075	.069	.064	.059	.053	
.60	.044	.039	.033	.028	.023	.018	.013	.008	
.65	.004	.002	.006	.011	.016	.021	.026	.031	Subtract for quantities below line.
.70	.033	.040	.043	.048	.053	.057	.062	.067	
.75	.066	.073	.076	.080	.085	.090	.094	.099	
.80	.096	.102	.105	.110	.114	.118	.123	.127	
.90	.148	.154	.157	.161	.165	.169	.173	.178	
1.00	.192	.197	.200	.204	.207	.211	.215	.219	

TABLE V.

For Determining the Temperature of Flowing Gas from the Temperature Observed on the Encased Thermometer, as in Fig. 6.

Observed pressure by pressure-gauge as in Fig. 4—lbs. per square inch.	Observed temperature given by the encased thermometer.										
	30°.	50°.	80°.	120°.	160°.	200°.	240°.	280°.	320°.	360°.	400°.
0.5	25	45	.....	.....	.....	.....	.....	.....	.....	.....	.....
.75	23	42	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.0	21	40	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.5	.....	36	65	.....	.....	.....	.....	.....	.....	.....	.....
2.0	.....	32	60	.....	.....	.....	.....	.....	.....	.....	.....
2.5	.....	27	56	.....	.....	.....	.....	.....	.....	.....	.....
3.0	.....	23	52	.....	.....	.....	.....	.....	.....	.....	.....
3.5	.....	19	48	.....	.....	.....	.....	.....	.....	.....	.....
4.0	.....	15	43	.....	.....	.....	.....	.....	.....	.....	.....
4.5	.....	11	39	.....	.....	.....	.....	.....	.....	.....	.....
5.0	.....	.....	36	72	.....	.....	.....	.....	.....	.....	.....
5.5	.....	.....	32	68	.....	.....	.....	.....	.....	.....	.....
6.0	.....	.....	28	65	.....	.....	.....	.....	.....	.....	.....
6.5	.....	.....	25	62	.....	.....	.....	.....	.....	.....	.....
7.0	.....	.....	22	58	.....	.....	.....	.....	.....	.....	.....
7.5	.....	.....	19	54	.....	.....	.....	.....	.....	.....	.....
8.0	.....	.....	16	51	.....	.....	.....	.....	.....	.....	.....
9.0	.....	.....	.....	44	79	.....	.....	.....	.....	.....	.....
10.0	.....	.....	.....	39	73	.....	.....	.....	.....	.....	.....
12.0	.....	.....	.....	29	62	.....	.....	.....	.....	.....	.....
14.0	.....	.....	.....	18	51	.....	.....	.....	.....	.....	.....
16.0	.....	.....	.....	.....	41	72	.....	.....	.....	.....	.....
18.0	.....	.....	.....	.....	31	63	.....	.....	.....	.....	.....
20.0	.....	.....	.....	.....	22	54	.....	.....	.....	.....	.....
25.0	.....	.....	.....	.....	.....	35	64	.....	.....	.....	.....
30.0	.....	.....	.....	.....	.....	17	46	75	.....	.....	.....
35.0	.....	.....	.....	.....	.....	.....	30	59	.....	.....	.....
40.0	.....	.....	.....	.....	.....	.....	16	44	72	.....	.....
45.0	.....	.....	.....	.....	.....	.....	.....	32	60	.....	.....
50.0	.....	.....	.....	.....	.....	.....	.....	20	48	.....	.....
55.0	.....	.....	.....	.....	.....	.....	.....	.....	36	61	.....
60.0	.....	.....	.....	.....	.....	.....	.....	.....	25	51	75

Table V is for use when the encased thermometer is used for determining the temperature of flowing gas through the well-mouth. In most cases this observation may not be required, as this temperature can be approximated by observing the well. When ice forms around the well-pipe the temperature will be not far from 32° F, probably, though this observation should be taken not immediately at a discharging-mouth, but some feet below.

The practice of opening a cock for gas to flow out from a high pressure, in which jet to insert the thermometer, will not answer by any means, for two reasons: 1st, because of the great cooling of gas

with sudden expansion, and 2d, because the striking of gas particles against the thermometer bulb will have the effect to heat it, thus affecting the thermometer readings by two very considerable causes of error. The thermometer may be introduced in the well-tube into the gas itself below the mouth for a tolerably close approximation to truth, but even the second cause named above will to some slight degree at least affect the thermometer. Probably the most practical way for closely approximating the temperature of flow, by other observations than the encased thermometer, would be by submerging the thermometer bulb in a puddle of water lying on the bare well-pipe below the mouth. To do this, get some moist clay and form a dam of it against the pipe large enough to receive the water, with one side of the pool of water against the pipe for vertical pipes, or the bottom of the pool on the pipe in horizontal pipes. In this pool or puddle of water place the thermometer bulb and allow it to stand some minutes before observing. Thus the water will take very nearly the temperature of the pipe, and also the thermometer bulb. In this case the temperature of the well-pipe is assumed to be the same as that of the flowing gas.

But the encased thermometer is the only scientifically correct means for determining the temperature of the flowing gas at the well-mouth.

Examples.

The following examples are worked out to illustrate the use of the tables:

1st. Take $p_1 - p_2$ = 10 lbs. per square inch by Pitot tube.
p_1 = 24.6 for flow into atmosphere.
$Sg.$ = .45.
Temperature flowing gas = 40° Fahr.
Temperature storage = 50° Fahr.
Diameter of pipe = 4 inches.

Then by calculation with the formulas direct, we obtain

v = 1453.9 feet per second,

and V. day = 11,180,000 cubic feet per day, as obtained without the use of the tables.

By Table II we obtain for the same example, the observed pressure being $p_1 - p_2$ = 10 lbs.

V. day = 9,428,000 cubic feet.

Then to correct this for the specific gravity 0.45, the temperature of

flowing gas 40° Fahr., and the temperature of storage of 50°, we obtain from Table IV the multiplier .188, additive, giving for the result sought:

V. day = 9,428,000 + 9,428,000 × .188

=11,200,500 cubic feet per day, which differs from the calculation above by only $\frac{1}{560}$th, an error of less than a fifth of one per cent.

2d example. Observed pressure $p_1 - p_2$ = 25 lbs. Pitot tube.

p_1 = 39.6 lbs. for flow into air.

$Sg.$ = 0.8

Temperature flowing gas = 30° Fahr.

Temperature storage = 50° Fahr.

Diameter pipe = 6 inches.

Then by formulas

v = 1542.3 feet per second.

V. day = 27,231,000 cubic feet per day.

By table II observed pressure being 25 lbs., V. day = 30,425,500 cubic feet, and from table IV we obtain the multiplier .102 subtractive, and finally the corrected value of V. day = 27,322,000 cubic feet per day, which is in error only a third of one per cent.

3d example. The Karg well, Findlay, O.:

Observed pressure $p_1 - p_2$ = 15. by Pitot tube.

Take $Sg.$ = 0.6

Temperature flowing gas = 32° Fahr.

Temperature storage = 50° Fahr.

Diameter pipe = 4 inches.

By table II, V. day = 11,107,500 for a temperature of storage at 32°. Correction for temperature of storage at 50°, table IV is .0366 × 11,107,500 additive = 406,534, which added, gives V. day = 11,514,034 cubic feet per day. This figure is less than the previously published figures, one reason being the fact that the figure 12 million, by calculation, was for a temperature of storage of 60°.

4th example. The Briggs well, Findlay, O.:

Observed pressure $p_1 - p_2$ = 6.5 lbs. by Pitot tube.

$Sg.$ = 0.6.

Temperature flowing gas = 32° Fahr.

Temperature storage = 50° Fahr.

Diameter pipe = $2\frac{1}{4}$ inches.

By table II, V. day = 2,510,700 cubic feet found by interpolating between 1,959,400 for a 2-inch mouth, and 3,062,000 for a $2\frac{1}{2}$-inch mouth.

By table IV the correction multiplier is .0366, found by interpolating for 32° between the value under 30° and 35°. The correction is

then 91,891 cubic feet, and the corrected value V. day = 2,602,591 cubic feet per day.

5th example. Jones well, Findlay, O.:

Observed pressure = 3.79 inches by water gauge.
$Sg.$ = 0.6.
Temperature flowing gas = 32° Fahr.
Temperature storage = 50° Fahr.
Diameter pipe = $3\frac{3}{8}$ inches.

By table II, V. day = 871,658 cubic feet, found by interpolating under d = 3 inches between observed pressures of 3 and 4 inches; also, by interpolating likewise under d = $3\frac{1}{2}$ inches, and then interpolating between the quantities thus obtained for the diameter $3\frac{3}{8}$ inches. Then by table IV the multiplier is .0366, giving a correction + 31,903, and the final results for a storage temperature of 50°, of V. day = 903,561 cubic feet per day.

II. PIPING OF GAS.

The recent rapidly increasing demand for natural gas at points comparatively remote from the gas-well districts has led to the piping of gas to such great distances as to render a knowledge of the capacity of long pipes for conducting gas a necessity.

It has been stated that the quantities of gas transferred in these long pipes considerably exceeds the amount determined by the ordinary formulas for calculating gas-flow in pipes.

The difficulty of obtaining accurate results on the flow has probably delayed definite knowledge on this important subject, the chief difficulty consisting of close determination of either the quantity of gas or of velocity. Probably the simplest way for reasonable accuracy is to determine the velocity directly by means of a Pitot tube placed in the stream of gas as it flows in the pipe, as suggested over a year ago, and stated under "applications" in this chapter.

Last spring, in accordance with this, some experiments were made with a Pitot tube placed in a pipe-line leading into Fostoria, by which velocities were determined in a 6-inch pipe under a fall of pressure of from one-third of a pound per square inch per mile, up to two pounds per mile, giving about thirty results for the coefficient of friction of natural gas in pipes. Two important facts were discovered from these results. First, the extraordinarily low value of the coefficient; and, second, that the smaller the fall of pressure per mile in the pipe, the lower the coefficient, while for a greater drop in pressure per mile, of say, eight or ten pounds per square inch, the coefficient approaches the usually accepted value.

For these experiments a portion of pipe-line, three miles long and six inches in diameter, was selected, at each end of which was placed an accurate pressure-gauge reading to single pounds and estimated to quarters, and a Pitot tube for measuring velocity. The gauges were carefully compared after the experiments by placing them both in common on a pressure apparatus, and reading them simultaneously. Corrections were made according to index errors thus determined.

The Pitot tube apparatus at one end was identically the same as that used at the other end of the three-mile length of the pipe-line experimented on. Each of these consisted of two tubes, about $\frac{1}{8}$ inch diameter, inclosed inside a 14-inch piece of $\frac{3}{8}$ inch gas-pipe, and plugged, so as to prevent gas from passing through, except in the two small pipes. The small pipes reached out about one inch distance at one end and were dressed square and beveled out to a sharp edge. One of these ends was bent to a right angle to form the Pitot tube-mouth proper, while the other was left straight for a "side outlet," so that, when the containing tube of this combined arrangement was inserted at right angles into the pipe-line main, the bent end could be presented square toward the current, while the straight end would serve as side outlet, as for the two openings in fig. 5, at A and B, respectively. Then, by properly directing the bent end, the stream of gas in the pipe would drive direct and square against it, while the straight end would receive the current square across, and be uninfluenced by the velocity of gas, and thus the straight end be influenced by only the statical pressure, while the bent end would be influenced by the statical pressure plus a pressure due to the velocity of the stream of gas, and by which excess the velocity was determined. The other end of this combination of tubes had a U-shaped water-manometer attached to the small tubes, one branch of the manometer to one, and the other branch to the other small pipe. In this way the statical pressure at one mouth in the stream of gas is balanced by the statical pressure at the other mouth, leaving to be read off from the manometer only the column of water which is due to the velocity of the current.

The containing tube, as above described, was made smooth outside and fitted to run through a packing joint so that the Pitot tube-mouth could be put to any point in the diameter of the main pipe of the pipe-line.

To mount this Pitot tube apparatus in serviceable connection with the pipe-main, a cock was tapped into the main, through the plug of which cock the mouth-end of the Pitot apparatus could be passed into the stream of gas. To the outer end of this cock was screwed a larger

pipe about six inches long, having the packing joint above mentioned at its outer end, through which the Pitot apparatus should slide. When the cock was once connected to the pipe-main, it is plain that the other portion of apparatus, above described, could be screwed on the cock and the cock opened and the Pitot tube-mouths inserted into the stream of gas for service in the experiments.

The pressure-gauge was also connected to these pipes outside of the cock so that the pressure could be read off to the fraction of a pound.

In these experiments it was necessary to have a pressure-gauge at each end of the portion of pipe experimented on but not the Pitot tube apparatus, the main object of the latter at each point of observation being to obtain a check of one or the other, and to obtain a mean of two readings for a single result.

The results obtained from the experiments on this 3-mile portion of line are given below, viz., where p_1 = the absolute pressure, pounds per square-inch, at upper end, p_2 = absolute pressure, pounds per square-inch at lower end of the 3 mile portion of pipe, and $p_1 - p_2$ = fall of pressure in three miles.

TABLE VI OF EXPERIMENTAL DATA OBTAINED FROM A THREE MILE PORTION OF A 6-INCH PIPE-LINE.*

No. of observations.	p_1 pounds.	p_2 pounds.	$p_1 + p_2$ pounds.	$p_1 - p_2$ pounds.	Coefficient friction, experiment.	Coefficient friction, calculated.	Observed inches of water by manometer.
4	99¼	98¼	197½	1	.0025	.0028	0.15
8	99¼	98	197¼	1¼	.0030	.....	0.15
7	99½	98	197½	1½	.0037	.....	0.15
2	99¾	98	179¾	1¾	.0043	.0028	0 15
2	97¼	95	192¼	2¼	.0052	.....	0.16
1	97½	95	192½	2½	.0059	.0030	0.16
	83¾	81¼	165	2½	.0053	.....	0.17
1	79¼	77	156¼	2¼	.0042	.0035	0.20
1	79¼	73½	152¾	5¾	.0070	.....	0.30
1	79¼	73	152¼	6¼	.0060	.....	0 50
1	79¼	73	152¼	6¼	.0048	.0050	0.50

*The experimental data of this table were obtained by Mr. H. E. Payne, M. E, for use in his graduating the is, class of '87, Ohio State University.

The values of the coefficient of friction are seen from this table to fall rapidly with the fall of pressure per mile, it being about up to the usually accepted value for one to two pounds drop in the pressure per mile, while for as low a fall of pressure in the pipe as one-third pound per mile, the coefficient goes down to less than a half of the usually assumed value .006. This makes an important difference in the amount of gas conveyed by the pipe, since the velocity of flow varies inversely as the square root of the coefficient of friction, making the cubic feet per hour of actual and calculated flow differ as 1.4 to 1 for coefficients of friction differing as 1 to 2, thus making the actual flow of gas in pipes, for low drops of pressure per mile, greater by neary fifty per cent. than results calculated by the ordinary formulas.

The coefficient of friction is found not to be constant for either water or air in previous experiments.

Thus, for values quoted in Van Nostrand's Engineering Magazine, for May, 1881, page 377, for a lead-pipe, one mile long and 1.25 inches diameter, conveying compressed air where the fall of pressure per mile varied from 12 to 1.75 pounds, the coefficient of friction varied from .0054 to .0023. Also in experiments at the St. Gothard Tunnel, in conveying compressed air through nearly 3 miles of $7\frac{5}{8}$-inch pipe, and for a fall of pressure per mile varying from 1.8 to 1 pound, the coefficient ranged at about .0034, and is nearly constant. Data stated from preliminaries to use of compressed air in the Mont Cenis Tunnel give the coefficient of friction at about .006 and constant, but I am not able to determine that these data are all experimental, and believe that only a very few experimental results, if any, were obtained, and the others stated by aid of laws of flow and constant coefficient f, for which reason those figures are not here quoted.

When all the above named *bona fide* results of experiment are plotted on a diagram where f is made to vary as velocity, or as fall of pressure per mile, or otherwise, they will not plot close to any curve, and probably as good an expression for f as can be found from these experimental data is the empirical one.

$$f = .00053\, v^{\frac{3}{4}} \qquad (24)$$

The calculated values of f, given in Table VI, are from this formula.

The agreement of the calculated coefficients f with those obtained from observation does not appear as close as desirable, but the fact of the delicacy of the experiments should be kept in mind. For instance, where the difference of pressure at points in a pipe three miles apart is only from one to two pounds for an absolute pressure of nearly 100

pounds per square inch; also where the static pressure of the stream of gas is equivalent to a column of water of 200 feet, while the column measured as due to velocity is only from .15 to .5 inch of water; the care and precision required in obtaining results, showing in every respect favorably, are seen to be great, and irregularities of results may not seem strange. In such case great accuracy is only obtained from averaging a long series of observations. Unaccountable discrepancies are also found in the coefficients f found from the St. Gothard experiments.

The manometric columns, noted in Table VI, were obtained from the velocity at the center of the pipe, which velocity must be considerably above the average for the section, as it is well known that in such a stream, as a fluid in a pipe, the velocity is much less at the surface of the pipe than in its center. Observations were made at different points in the diameter by Mr. Payne, and these, combined with like experiments on the flow of air in pipes, gave a result of 1.7 as the ratio of the manometric columns from which the ratio of the maximum velocity to the mean velocity respectfully is to be obtained.

Formulas.

To find the velocity from the manometric column we have, for the Pitot tube, for slight changes of pressure as in the present case, the relation.

$$v^2 = 2gh \qquad (1)$$

where h is the head to be found in terms of the fluid flowing; that is, it is the height of a column of the fluid flowing as if of uniform density up to a free surface, as in the case of water flowing through an orifice. When h is given in terms of water, as in Table VI, it is to be multiplied by the ratio of densities of the water and flowing gas. That is

$$h = h_m \frac{\delta_m}{\delta} \qquad (25)$$

Thus, if the specific gravity of the gas is 0.6, its weight per cubic foot at atmospheric pressure, and at the temperature of melting ice, is

$$0.0807 \times .6 = .04842,$$

and for five atmospheres of absolute pressure as in the lowest line in Table VI, the weight per cubic foot will be

$$.04842 \times 5 = 0.24210,$$

and h for the same experiment will be

$$h = \frac{.50}{12} \frac{62.5}{.2421} = 10.8 \text{ feet},$$

where the 62.5 is the weight of a cubic foot of water, water being the fluid used in the manometer.

The velocity is $V = 8\sqrt{10.8} = 26.3$ feet per second.

In this way the velocities were obtained from which to calculate the coefficients f of Table VI, except the manometer heads were first divided by 1.7 in order to give the mean velocities.

The flow in long pipes, like natural gas pipe lines, will be approximately isothermal; that is, though the gas will expand as it flows along, and become cooled by such expansion, unless protected by non-conductors, yet in an iron pipe, buried in earth, the pipe can readily impart heat to warm the gas as it cools. The work done by the expansion of the gas will aid in overcoming the resistance to flow, as well as the difference of pressure in the pipe at opposite ends. A formula, taking account of all the components producing motion, as well as all the resistances to flow in a pipe for this case, is

$$\frac{v^2}{2g} = \frac{d}{8fl}\frac{p_2}{\delta_2}\left\{\left(\frac{p_1}{p_2}\right)^2 - 1\right\} \qquad (26)$$

where v = mean velocity at "down-stream" end of pipe, feet per second.

g = acceleration of gravity = 32.2 feet.

d = diameter of pipe, in feet, inside.

f = coefficient of friction from formula above.

l = length of pipe in feet.

δ_2 = weight per cubic ft. of flowing gas at down-stream end of pipe.

p_1 = absolute pressure at upper end of pipe considered, pounds per square-foot.

p_2 = like pressure at down-stream end of pipe.

By putting the value of f from the formula 24, in this last equation, we obtain

$$v^{\frac{11}{4}} = \frac{gd(p_1 - p_2)(p_1 + p_2)}{4l\delta_2 p_2 0.00053} \qquad (27)$$

$$\frac{p_2}{\delta_2} = \frac{p_0 \tau_2}{\delta_0 \tau_0}$$

$$\text{V.hour} = 567.5\left\{\left(\frac{p_1}{p_2}\right)^2 - 1\right\}^{\frac{4}{11}} d^{\frac{26}{11}}\left(\frac{\tau_2}{\tau_0}\right)^{\frac{4}{11}} \qquad (28)$$

giving the cubic feet transferred by the pipe per hour, in which

τ_0 = the absolute temperature of melting ice = 493.2 Fahr.

τ_2 = " " flowing gas.

Tables.

From this formula, Table VII was calculated, giving the cubic feet of natural gas conveyed by a pipe-line in terms of the diameter; and fall of pressure per mile, divided by the absolute pressure of gas at the exit end, or at the "down-stream" end of that portion of pipe considered.

Example of the use of Table VII:

Fall of pressure for last mile, 1.925 pounds. Gauge pressure (apparent pressure) at down-stream end, fifty pounds, and diameter of pipe, eight inches.

Then $\frac{1.925}{14.6 + 50} = \frac{1.925}{64.6} = .029$

to look for in the first column. The figure is to be found one-fifth the way from the value under eight inches and opposite .029, toward the value opposite .033, which is 28,274 cubic feet per hour.

To correct the quantities taken from Table VII for other temperatures and specific gravities of flow than 50° F., and 0.6 specific gravity, Table VIII of multipliers is to be used:

TABLE VII.

CUBIC FEET OF GAS CONVEYED BY A PIPE-LINE, PER HOUR, OF UNIFORM FLOW; FOR A TEMPERATURE OF FLOWING GAS OF 50° FAHR., AND SPECIFIC GRAVITY OF 0.6. FOR OTHER TEMPERATURES AND DENSITIES OF FLOWING GAS CORRECT BY AID OF TABLE VIII. THE VOLUME THUS OBTAINED IS AT THE OBSERVED PRESSURE IN THE PIPE AT THE "DOWN-STREAM" END, AND MUST BE EXPANDED BY AID OF TABLE IX TO OBTAIN THE VOL. AT ATMOSPHERIC PRESSURE.

THE FIRST COLUMN GIVES $\frac{\text{"FALL LAST MILE,"}}{14.6 + \text{LOWER GAUGE PRESSURE}}$ WHICH MEANS THE FALL OF PRESSURE ALONG THE PIPE FOR THE LAST MILE; DIVIDED BY 14.6, PLUS THE GAUGE PRESSURE (APPARENT PRESSURE), AT DOWN-STREAM END OF PIPE. THUS, IF THE PRESSURE OF THE GAS IN THE PIPE DIMINISHES THREE POUNDS IN THE LAST MILE, AND IF THE GAUGE PRESSURE IN THE PIPE AT THE DOWN-STREAM END IS 45.4 POUNDS PER SQUARE-INCH, THEN THE VALUE TO LOOK FOR IN THE FIRST COLUMN OF TABLE IS $\frac{3}{14.6 + 45.4} = .05$. FOR ATMOSPHERIC VOLUME SEE TABLE IX.

Fall last mile / 14.6 + lower gauge pressure.	Inside diameter of pipe-line in inches.											
	2-in.	4 in.	6-in.	8-in.	10-in.	12-in.	14-in.	16-in.	18-in.	20-in.	24-in.	30-in.
0.005	548	2,819	7,351	14,510	24,588	37,834	54,328	74,680	98,650	126,550	194,720	329,960
0.006	585	3,013	7,856	15,007	26,278	40,434	58,063	79,810	105,430	135,250	208,100	352,640
0.007	619	3,187	8,330	16,404	27,800	42,770	61,420	84,430	111,530	143,070	220,140	373,040
0.008	650	3,346	8,726	17,220	29,190	44,900	64,490	88,640	117,100	150,210	231,130	391,670
0.009	676	3,480	9,070	17,900	30,342	46,690	67,040	92,145	121,730	156,160	240,280	407,180
0.010	705	3,630	9,470	18,690	31,660	48,720	69,970	96,170	127,040	162,970	250,760	424,940
0.014	818	4,212	10,980	21,680	36,730	56,510	81,150	111,560	147,360	189,030	290,860	492,890
0.019	909	4,680	12,200	24,080	40,820	62,800	90,185	123,960	163,760	210,060	323,230	547,740
0.024	987	5,088	13,240	26,150	44,307	68,174	97,896	134,550	177,760	228,020	350,970	594,570
0.029	1,056	5,433	14,170	27,960	47,390	72,920	104,700	143,910	190,120	243,880	375,260	635 900
0.033	1,117	5,750	15,000	29,530	50,160	77,180	110,840	152,350	201,260	258 170	397.240	673,160
0.038	1,175	6 040	15,760	31,100	52,700	81,100	116,480	160,070	211,450	271,250	417.380	707,280
0.043	1,227	6,310	16,460	32,500	55,060	84,720	121,660	167,230	220,910	283,380	436,040	738,900

0.048	1,275	6,565	17,110	33,800	57,260	88,110	126,520	173,910	229,740	291 710	453,470	768,430
0.058	1,364	7,020	18 310	36,150	61,300	94,270	135,450	185,720	245,920	305,490	485,360	822,840
0.068	1,447	7,447	19,410	38,320	64,940	99 930	143,500	197,240	260 56)	334,240	514,300	871,520
0.077	1 520	7,831	20,420	40,300	69,900	105,100	150.880	207,4 20	274,000	351,500	540,840	916,400
0.087	1,59)	8,190	21,350	42,140	71.410	109 870	157,780	216,870	286,500	367.510	565,490	958,270
0 096	1.620	8,520	22,220	43,860	74,330	114 360	164,220	225,730	298,220	382,530	588,600	997,400
0.116	1,775	9,137	23,830	47.030	79,690	122,630	176,090	242,040	319.74)	410,160	631.110	1,069,500
0.136	1,884	9,697	25,280	49,910	84,570	130,140	186 880	256,870	339.330	435,290	669,790	1,135,000
0.155	1,985	10,210	26,630	52,572	89,080	137,080	196,840	270,570	357,420	458 500	70 5,490	1,195,500
0.174	2,077	10,690	27,880	55,030	93,250	143,480	206,050	283,230	374,140	479,950	739,520	1,251,430
0.194	2,166	11,150	29,065	57,370	97,220	149,600	214,800	295,300	390,100	500 3 0	769,900	1,3 04,500
0.213	2,250	11,580	30,200	59,620	101,000	155 5 0	223,200	306 900	405 900	520,000	800,100	1 355.000
0.233	2,330	12,000	31,262	61,700	104,560	160,890	231,600	317,600	419.500	538,200	828 070	1,403,300
0.252	2,404	12,370	32,260	63 680	107,910	166.050	238,450	327,760	432 980	555 410	854 600	1,448.000
0.272	2,480	12,770	33,280	65 680	111,300	171,200	246,000	345,900	446,550	572.900	881.500	1,493,600
0.291	2,550	13,140	34,250	67,690	114,6 0	176,300	253,1 0 0	347,900	459,600	589,500	907,200	1,537,300
0.485	3,153	16,220	42,310	83,520	141,130	217,800	312,700	429,800	567,800	728,300	1,120,800	1,899,100

TABLE VIII.

MULTIPLIERS FOR CORRECTING QUANTITIES TAKEN FROM TABLE VII, FOR CASES WHERE THE ACTUAL SPECIFIC GRAVITY OF THE GAS IS NOT 0 6; AND ACTUAL TEMPERATURE OF FLOWING GAS NOT 50° F.; FOR OBTAINING THE VOLUME AT THE STANDARD "STORAGE TEMPERATURE" OF 50°, BUT WHICH IS STILL AT THE OBSERVED GAUGE PRESSURE OF THE "DOWN-STREAM" END OF PIPE. TO CHANGE THIS VOLUME TO THAT AT ATMOSPHERIC PRESSURE, OR TO THAT AT ANY STANDARD "SERVICE PRESSURE," SEE TABLE IX.

To use this table, multiply the quantity from Table VII by the value obtained from this table, and add or subtract, as the case may be.

Observed Temperature flowing gas.	Specific gravity of the gas (air being 1).						
	0.4	0.5	0.6	0.7	0.8	0.9	1.0
25	.199	.105	.033	.019	.070	.109	.143
30	.192	.097	.026	.026	.077	.114	.149
35	.184	.091	.019	.032	.083	.120	.154
40	.177	.085	.013	.038	.089	.126	.159
45	.169	.078	.007	.043	.094	.131	.164
50	.161	.071	.000	.050	.100	.137	.169
55	.154	.064	.006	.056	.105	.142	.174
60	.147	.058	.011	.061	.110	.147	.179
65	.140	.052	.016	.066	.115	.152	.183
70	.133	.046	.021	.071	.120	.157	.187
75	.126	.040	.026	.076	.125	.162	.191
80	.120	.034	.032	.081	.130	.167	.196
	add correction.			subtract correction.			

Example of use of Table VIII: 1st. Correct the value 28,274 cubic feet of the above example for a temperature of flowing gas of 60°.

Then the correct value is 28,274 — 28,274 × .011 = 28,274 — 311 = 27,963 for the correct cubic feet per hour at 50° F., and at the observed pressure.

2d. Suppose the temperature of flow were 39° F. and the specific gravity of gas were 0 8, then the multiplier from Table VIII is .088, and to correct the above cubic feet per hour we have the correction = 28,274 × .088 = 2477, subtractive, and hence the corrected cubic feet per hour is 25,797 cubic feet, also at 50° F., and observed pressure (apparent) by gauge of 50 pounds.

It is to be noted that the gas, as above determined, is at the observed pressure of the flowing gas at the down-stream end of the portion of pipe-line observed, and hence, if this pressure is considerable, the density of the gas may be several times as great as it would be if at

atmospheric pressure. Table IX is introduced to make correction for this, and to reduce the gas to the "storage pressure" of the atmosphere as though the gas were stored in an ordinary gas holder.

In practice it may be desirable to supply the gas to consumers by meter, and at a pressure of one pound or four pounds, etc., per square-inch, as the case may be.

Table IX may be used to reduce to any such specified pressure, by correcting back from atmospheric pressure to the one pound or four pounds, etc.

Thus suppose an observed pressure of fifty pounds. Then multiply by 4.425 reducing to atmospheric pressure. Then divide by 1.274 to correct back to a service pressure of four pounds per square inch.

TABLE IX.

MULTIPLIERS CHANGING THE VOL. OF GAS FROM THAT AT THE OBSERVED PRESSURE AT THE "DOWN-STREAM" END OF PIPE, AS GIVEN BY TABLES VII AND VIII, TO THAT AT ATMOSPHERIC PRESSURE AS THOUGH STORED IN A GAS-HOLDER. THUS, IF THE OBSERVED PRESSURE IS 30 POUNDS, TABLES VII AND VIII GIVE ONLY ABOUT ONE-THIRD THE ATMOSPHERIC VOLUME.

Observed pressure by gauge at down-stream end.	Multiplier to give volume, at atmospheric pressure.	Observed pressure by gauge at down-stream end.	Multiplier to give volume at atmospheric pressure.	Observed pressure by gauge at down-stream end.	Multiplier to give volume at atmospheric pressure.	Observed pressure by gauge at down-stream end.	Multiplier to give volume at atmospheric pressure.
2	1.137	30	3.055	70	5.795	180	13.330
4	1.274	32	3.192	75	6.137	190	14.015
6	1.411	34	3.329	80	6.480	200	14.700
8	1.548	36	3.466	85	6.822	220	16.070
10	1.685	38	3.603	90	7.165	240	17.440
12	1.822	40	3.740	95	7.507	260	18.810
14	1.959	42	3.877	100	7.850	280	20.180
16	2.096	44	4.014	110	8.535	300	21.550
18	2.233	46	4.151	120	9.220	320	22.920
20	2.370	48	4.288	130	9.905	340	24.290
22	2.507	50	4.425	140	10.590	360	25.660
24	2.644	55	4.767	150	11.275	400	28.400
26	2.781	60	5.110	160	11.960	450	31.825
28	2.918	65	5.452	170	12.645	500	35.250

TABLE X.

FOR FINDING THE TOTAL FALL OF PRESSURE FOR A LONG PIPE-LINE, WHEN THE FALL OF PRESSURE FOR THE LAST MILE OF THE SAME LINE IS KNOWN, AND *vice versa*. OR, MORE GENERALLY, TO FIND THE FALL OF PRESSURE FOR ANY LENGTH OF LINE WHEN THE FALL FOR A GIVEN LENGTH OF THE SAME LINE IS KNOWN.

Thus, suppose a pipe-line ten miles long, and that the fall for the last mile is 12.4 pounds, and the observed pressure by gauge (apparent pressure), at the lower end of the last mile is 65.4 pounds, then 12.4 pounds divided by the sum 14.6, plus 65.4, gives $\frac{12.4}{80} = .155$, for the value to look for in the first column. Opposite this, under ten miles, find 1.083, which equals the fall of pressure for the whole ten miles, divided by the sum 14.6 plus 65.4 $= \frac{86.64}{80}$. Hence, the fall of pressure for the whole ten miles is $1.083 \times (14.6 + 65.4) = 1.083 \times 80 =$ 86.64 pounds, when the fall for the last mile is 12.4 pounds.

Again, if the pipe-line be sixty miles long with the same pressures for the last mile, then the fall for the sixty miles will be the table value, $7.565 \times 80 = 605.2$ pounds.

Fall last mile. 1.46 + observed gauge pressure.	Length of the long Natural Gas-pipe Line in miles.													
	2.	4.	6.	8.	10.	12.	16.	20.	30.	40.	50.	60.	80.	100.
.005	.010	.019	.028	.038	.046	.056	.073	.092	.133	.175	.216	.254	.330	.400
.006	.012	.023	.033	.046	.056	.067	.088	.109	.159	.208	.257	.301	.390	.469
.007	.014	.026	.039	.054	.065	.078	.102	.127	.185	.241	.294	346	.444	.534
.008	.016	.030	.045	.059	.074	.088	.116	.144	.209	.272	.331	.389	.497	.597
.009	.018	.034	.051	.068	.083	.099	.131	.162	.234	.303	.368	.431	.550	.661
.010	.019	.037	.056	.075	.092	.110	.144	.176	.257	.332	.403	.471	.598	.715
.014	.029	.057	.084	.110	.136	.162	.212	.260	.370	.473	.568	.660	.829	.981
.019	.039	.075	.111	.145	.180	.213	.276	.337	.474	.603	.719	.830	1.033	1.217
.024	.047	.095	.138	.179	.220	.261	.337	.409	.572	.721	.857	.986	1.219	1 430
.029	.057	.111	.164	.212	.260	.308	.396	.478	.664	.835	.986	1.131	1.391	1.627
.033	.067	.130	.189	.245	.299	.353	.452	.543	.752	.942	1.108	1.268	1 552	1.810
038	.076	.147	.214	.277	.338	.397	.513	.606	.836	1.038	1.223	1 395	1 704	1.983
.043	.085	.164	.238	.308	.375	.439	.557	.667	.916	1.135	1.334	1.517	1.849	2.145

.048	.094	.181	.262	.338	.410	.479	.608	.726	.992	1.226	1.437	1.633	1.985	2.300
.058	.113	.216	.310	.398	.481	.560	.707	.842	1.140	1.402	1.639	1.858	2.247	2.596
.068	.132	.249	.357	.456	.550	.636	.801	.950	1.272	1.566	1.829	2.066	2.442	2.876
.077	.151	.282	.402	.513	.615	.711	.891	1.057	1.412	1.723	2.005	2.261	2.720	3.131
.087	.168	.314	.446	.567	.678	.783	.976	1.153	1.540	1.874	2.173	2.444	2.939	3.374
.096	.186	.346	.489	.619	.740	.852	1.059	1.245	1.665	2.016	2.335	2.626	3.146	3.610
.116	.221	.408	.573	.722	.860	.987	1.220	1.431	1.892	2.289	2.644	2.966	3.543	4.055
.136	.257	.469	.655	.822	.974	1.117	1.374	1.607	2.111	2.545	2.932	3.285	3.913	4.490
.155	.292	.529	.735	.916	1.083	1.239	1.519	1.773	2.320	2.788	3.207	3.587	4.264	4.864
.174	.328	.588	.812	1.008	1.189	1.357	1.660	1.934	2.521	3.021	3.468	3.874	4.599	4.238
.194	.362	.645	.886	1.098	1.293	1.476	1.796	2.084	2.710	3.243	3.720	4.150	4.919	5.597
.213	.396	.702	.959	1.185	1.394	1.584	1.927	2.232	2.896	3.457	3.962	4.415	5.226	5.941
.233	.429	.756	1.030	1.270	1.480	1.692	2.052	2.376	3.073	3.666	4.194	4.672	5.422	6.276
.252	.462	.810	1.100	1.363	1.585	1.797	2.175	2.517	3.246	3.869	4.421	4.922	5.812	6.601
.272	.495	.862	1.168	1.435	1.677	1.899	2.297	2.653	3.415	4.065	4.642	5.165	6.094	6.914
.291	.527	.914	1.235	1.516	1.767	2.099	2.417	2.786	3.580	4.257	4.847	5.400	6.369	7.222
.485	.847	1.417	1.875	2.268	2.616	2.934	3.506	4.012	5.100	6.017	6.831	7.565	8.873	10.030

To Determine a Pipe Line.

In the above tables we find the relation between the diameter of pipe, cubic feet per hour, fall of pressure per mile, and the gauge pressure of the flowing gas in the pipe at the lower end of that mile. But it is to be observed that the fall of pressure per mile is not the same for each mile of a long pipe-line of uniform size carrying gas in continuity of flow. Thus, if the drop in pressure in one mile, in such a pipe, is one pound, it will not be fifty pounds in the same pipe line fifty miles long. To determine the fall of pressure in a long line of many miles for a given diameter and flow, is the object of Table X, as more fully indicated below.

To explain Table X more fully, it should be noted that this, as well as Tables VII and VIII, are only applicable to a pipe-line of uniform size for the length considered, and for the suppositions of uniformity or continuity of flow.

In working out a long pipe-line of several sizes of pipe, each size must be taken by itself, and the several results of fall of pressure for each added.

In the first column of the Tables VII and X the same figures are intentionally given for the purpose of facilitating passing from one table to the other, thus connecting more directly the diameter of pipe and cubic feet of discharge, with the length and total fall of pressure.

To show the application of the tables the following examples are given:

1st. Example: Required the cubic feet of gas discharged by a pipe-line twenty miles long and six inches in diameter throughout, where the fall of gauge-pressure is from 200 pounds per square-inch to 40 pounds per square-inch; the forty pounds being, of course, marked by the gauge at the down stream end of the pipe-line, and the temperature of flowing gas being taken at 50° Fahr.

The total fall of pressure is $200 - 40 = 160$ pounds; and this, divided by $14.6 + 40 = 54.6$, is $\frac{160}{54.6} = 2.936$, which figure is to be looked for in Table X in the column under the stated length twenty miles. It lies between the figures 2.786 and 4.012, and about one-eighth the way from the first toward the second. Hence, the figure in the first column will be one-eighth the way from .291 toward .485. Passing to Table VII we find the same figures in the first column. Hence, the required cubic feet is at the one-eighth point between the two lower values of the table, and under the stated diameter six inches. Hence, the cubic feet discharged by the pipe per hour is 35,257.

But it is to be observed that this volume is at the temperature of 50° Fahr., and at the gauge-pressure of forty pounds per square-inch, as the volume given by Table VII is at the pressure of the flowing gas at the down stream end of pipe, forty pounds by gauge in this case.

To change this to the volume at atmospheric pressure, or "storage pressure." Tables IX gives the multiplier, 3.740, which, multiplied by the above volume 35,257, gives 131,861 cubic feet per hour, as the volume of gas that would be discharged by the pipe-line into a gas-holder at atmospheric pressure and at a temperature of 50° Fahr.

2d. Example: Required the fall of pressure in a pipe-line eighty miles long and eighteen inches in diameter that will deliver 6,564,285

cubic feet per hour of gas at atmospheric pressure, and 50° temperature, the gauge-pressure at the down stream end of pipe being taken at 200 pounds per square-inch.

To change this atmospheric pressure-volume to that of 200 pounds by gauge, Table IX gives the multiplier 14.7, which is now to be used as a divisor. Dividing and we obtain 446,550 cubic feet for the volume per hour at the 200-pound gauge-pressure.

Table VII, in the column under eighteen inches diameter, gives the figure 446,550 in the third line from the bottom, and opposite the figure .272 in the first column.

Then, looking in Table X, opposite the first column figure .272, and in the column for the stated length of line, eighty miles, we find the value 6.094, which is to be multiplied by the 200 pounds gauge pressure plus 14.6 pounds = 214.6 pounds or $214.6 \times 6.094 = 1308.$ pounds, as the fall of pressure for the eighty miles of eighteen-inch pipe-line. Adding the 200 pounds and we obtain the 1,508 pounds gauge pressure for the gas at entrance into the eighty mile-line.

3d example: Pipe-line in two sizes, viz., forty miles of four-inch pipe discharging into twenty miles of six-inch pipe.

Gauge pressure at delivery end of six-inch pipe, thirty pounds; cubic feet discharged 40,000 per hour at atmospheric pressure and temperature of 50° Fahr.

Temperature of flowing gas in the pipes 65°, and specific gravity of gas, 0.8.

Table IX, multiplier . . 3.055. Dividing 40,000, gives 13,098 cubic feet at thirty pounds pressure and 50° temperature.

Table VIII multiplier for 65° temperature of flow and 0.8 specific gravity is .115, and the correction $13,098 \times .115 = 1,470$, which we now add, because working backwards relative to application of Table VIII, giving 14,568 cubic feet to be discharged at the lower end of the six-inch pipe at the gauge pressure thirty pounds and temperature 65° Fahr.

Table VII, under six-inch pipe, the figure 14,568 comes opposite the value .031 in first column.

Table X, under twenty miles, we find just above top figure opposite .031 the value .176. Fall of pressure in the twenty mile six-inch pipe $= (30 + 14.6) \times .176 = 7.85$ pounds.

Gauge pressure at upper end of six-inch pipe or lower end of four-inch pipe = 37.85 pounds, and the cubic feet, by aid of Table IX,

$$= 14{,}568 \ \frac{3.055}{3.593} = 11{,}760.$$

Table VII, under four-inch pipe, the figure 11,760 comes opposite the value .222 in the first column.

Table X, opposite .222 and under forty miles, we get 3,560 to multiply into 37.85 to give the fall of pressure in the four-inch pipe, which = 135. pounds.

Hence, gauge pressure at entrance into the four-inch pipe = 135 + 37.85 = 172.85 pounds. Total fall of pressure in both pipes = 135. + 7.85 = 142.85 pounds.

Acknowledgments are due to B. G. Lamme, a student in the Department of Mechanical Engineering in the State University, for efficient aid in working out most of the tables of this chapter.

CHAPTER X.

THE PITTSBURGH COAL SEAM IN JEFFERSON, BELMONT AND GUERNSEY COUNTIES.

By Professor C. Newton Brown, Ohio State University.

The Pittsburgh coal seam (No. 8 coal of Newberry's scale) is the most important found in the Upper Coal Measures of the state. It lies from 190 feet to 210 feet above the Ames or Crinoidal limestone, and from 80 feet to 100 feet below the Meigs Creek coal, and forms the base of the Upper Coal Measures.

There are two areas in the state where it is mined in a large way, both for local use and shipment by railway and river. The largest and most important of these cover parts of Jefferson, Harrison, Belmont and Guernsey counties. The other covers parts of Athens, Meigs and Gallia counties, where it is known as the Pomeroy coal. Only that portion in Jefferson, Belmont and Guernsey counties is touched in this chapter.

Through this area the coal is remarkable for its regularity in quality, thickness, structure and freedom from wants, clay-veins and horse-backs.

There are usually two partings that divide the seam into three benches. The lower parting—from twelve to fourteen inches from the bottom—is a thin, black slate, sometimes carrying balls of pyrites in it.

The other parting is at, or a little above, the center. It is usually made up of two bands of clay with two to four inches of coal between them, the entire parting being from five to six inches thick. The bearing-in is frequently made at this place.

There is a coal from one to three feet thick, of poor quality, above the main coal and separated from it by about twelve inches of clay. The clay comes down as soon as the main coal is mined out and the thin coal above left for a roof. Above the roof coal is a bed of clay shale several feet thick, and under the main coal is a thin bed of clay underlaid by a bed of non-fossiliferous limestone.

This coal-field is crossed by five lines of railroad and bounded on

the east by the Ohio River, so that there are ample facilities for putting this coal in any of the northern, western or southern markets.

The coal is used mostly for household fuel, steam generation, gas-making, and in the manufacture of glass, pottery and iron. Little of it is worked into coke or used for smelting iron.

The facts pertaining to the distribution of this seam are shown in the map that accompanies this volume.

Jefferson County.

Knox Township.—The most northern showing of the Pittsburgh coal, in Jefferson county, is found in Knox township in the high land south of Yellow Creek. At Knoxville, and a short distance northeast in the highest hill-tops towards McCoy's station, are found small areas of the coal. It has a light covering and gives but little good clean coal. The thickness given is about four feet with the usual partings.

Ross Township.—There is a small number of isolated areas of this coal along the south side of Ross township, in Bacon Ridge, between Long Run and Town Fork of Yellow Creek, extending into the northwest corner of Salem township.

Springfield Township.—Near East Springfield the ridge carries several good-sized outliers of coal. The coal here is near the top of the hill. It has been worked for the local trade for a number of years, and is reported as being about four feet thick. The same ridge also extends past East Springfield through the southeast corner of Springfield township, and contains a few small areas of the coal.

Salem Township.—At Richmond, in the eastern part of Salem township, is found a considerable area of the coal. This is a high point from which the water flows into Yellow Creek, Island Creek and Cross Creek. A few mines about Richmond supply the local trade and much of the southern and western parts of the township. In S. W. quarter, section 3, Salem township, the following section was measured:

Hill above coal	About 50 feet.
Roof coal	——————.
Soap stone	About 24 inches.
Coal	20–21 inches.
Clay	1 inch.
Coal	3 inches.
Slate	¼–½ inch.
Coal	14 inches.
Black slate	½ inch.
Coal	12 inches.
Clay	——————.

Above the coal the following section was taken with the barometer:

Clay shale	10 feet or more.
Coal	12–24 inches.
Limestone	20–25 feet.
Roof coal	———

Just east of Richmond the coal was seen with the same thick bed of limestone over it.

Island Creek Township has the coal in three high ridges in the southwestern part, a few outliers in the northwest corner, and a number of small, unimportant areas in the central part, between Island Creek and north branch of Wills Creek. The coal is usually reported four feet thick, but is sometimes less. The bed of limestone and coal blossom above the No. 8 coal was noticed through this township.

Wayne Township.—None of the Pittsburgh coal is found north of the P., C. & St. L. Ry. in this township, but all the high ridges south of the railroad contain it. It is opened for local use at many points in the township. The coal is reported at from 4 feet 2 inches to 4 feet 10 inches in thickness in the western part. The roof coal is sometimes wanting, but usually the coal with its partings and roof is very regular. In some mines many balls of pyrites are found, while in others they are rare. They can usually be easily separated from the coal. Although Wayne township shows a large area of coal, the proportion of poor crop coal to the good coal is very large; for the coal is so near the tops of the hills and the slopes are so flat that it requires a considerable distance to get under good cover.

Cross Creek Township.—All of this township except the northwest quarter is very well supplied with the Pittsburgh coal. It is high in the hills and seldom has more than 100 feet of cover. It is mined at Wintersville, on the north line of the township, by a shaft about seventy feet deep, which shows the following section:

Earth	10 feet.
Shale	20 "
Coal	1 "
Shale	24 "
Limestone	15 "
Coal No. 8, roof coal, etc.	7 "
Clay	1 "
Limestone	1 "

The bed of limestone and shale above the coal is found throughout the northern part of this township. The Ames limestone is found 4 to 6 feet thick in sections 35 and 36 of this township. It is also fonnd in the eastern part, but is not so well shown. It is by barometer from 200 to

225 feet below the Pittsburgh coal. The coal has been worked at a number of points in the southeastern part for local use, and also for the village of New Alexandria. It is reported from 4 to 5 feet thick, with the usual partings and roof coal. The most of the pyrites is here found near the lower parting, where it is also found farther south in both Jefferson and Belmont counties.

Steubenville Township.—The largest area of Pittsburgh coal in this township is in sections 33, 34, 27 and 28, and a few acres in 35, 31 and 32. It is reported that all the coal has been worked out of section 28, and much of it from 27 and 33. It has been worked for many years for use in Steubenville and Mingo. A few mines in sections 34 and 35 and in the edge of Cross Creek township still find a market for their coal in Steubenville, and in the villages of Fisherville and Jeffersonville. At Tweed's mine, in N. W. quarter section 34, the following section was measured:

Coal (reported) 6 feet above top of main vein	8 inches.	
Clay shale	3–4 feet.	
Roof coal	2–3 "	
Soapstone or clay, average	12 inches.	
Hard black slate	0–4 "	
Coal	26½ "	5 feet.
Slate parting	¼–1½ "	
Coal	2 "	
Black slate	½–2 "	
Coal	16 "	
Black slate	⅛ inch.	
Coal	12½ in's.	
Clay	4 "	
Limestone	6–8 "	
Clay	6 "	
Limestone, exposed	36 "	

The limestone over the coal does not appear here, although it was seen in the southern part of the township. This mine has been opened but a short time, and has but a few rooms turned. Three clay veins have been found, but no "horsebacks." The soapstone or clay over the coal is taken down as fast as the coal is removed; it is full of slips or "slickensides," and makes a very dangerous roof. The roof coal makes a very excellent roof. Rooms have been driven 24 feet wide with few and very light posts, which have been standing more than a year, and show no signs of failing, although there are but 50 to 75 feet of cover over the coal. Pyrites balls are found, mostly in the top bench that is 26 inches thick. When pyrites is found in the lower part of the coal it is usually in the black slate parting, 12 inches from the bottom. At many of the mines about Steubenville the pyrites is carefully picked out and sold to the copperas works at Fisherville. It is worth 8 cents a bushel at the mouth of the mine.

The bearing-in is made in the central double parting and thin coal. The bottom is then shot and the top is wedged down. It is a good gas coal and cokes fairly, but contains considerable sulphur. Little or nothing is done in the way of coking it. Most of the slack is used for steam coal. The coal is very near the top of the high and very steep hills, and that makes the mines difficult of access with wagons. Several of the miners on Permar's Run have put up inclines and deliver the coal at the foot of the hill. The incline has three rails all the way down, except at the central part, where an automatic switch enables the loaded and empty cars to pass. The loaded cars pull the empty ones back to the top. The Ames Limestone is found at several points back of Steubenville and Mingo. It is by barometer from 210 to 220 feet below the coal. On Farmer's land at the centre of section 26 this limestone is found twelve inches thick. It is here 113 feet above the C. & P. R. R. track at Mingo Junction. On land belonging to Spaulding, Wood & Co., in the southern part of section 28, it is found in the bed of a small run, and measures from eighteen to twenty-four inches thick and 128 feet above the C. & P. R. R. track at Mingo Junction. These elevations were determined by the engineer's level and show a dip of fifteen feet in a distance of one and two-thirds miles due south.

Wells Township.—The larger part of this township holds the Pittsburgh coal, although it is very high in the hills. It has the usual roof coal separated from the main seam by the bed of soapstone about twelve inches thick. The roof coal varies considerably in thickness, ranging from six inches to five feet in different parts of the township; the usual thickness is from twelve inches to twenty-four inches. The main coal has the double parting near the centre and the small slate parting twelve inches to fourteen inches from the bottom. The entire seam ranges from four feet four inches to five feet thick. On Mrs. Riddle's land near the centre of section four, the coal is reported four feet six inches thick, and is 322 feet above the C. & P. R. R. track at Riddle Station. At Brilliant the coal at Gilchrist's Coal Works is reported five feet thick and having the usual parting. The roof coal is twelve inches above the main coal. The coal is here 343 feet above the C. & P. R. R. track at Brilliant Station.

The analysis of this coal is as follows: (*Lord*)

Moisture	1.83
Volatile combustible matter	40.06
Fixed carbon	50.09
Ash	7.02
Sulphur	3.31

In the small run back of Brilliant the Ames limestone is five feet thick in three ledges and has been worked and burned for lime. The lime was of poor quality, but that may have been due to the method of burning and testing it, which is reported to have been quite crude. The top of the Ames limestone is 105 feet above the track at Brilliant Station. The Pittsburgh coal is therefore 238 feet by the engineer's level above the Ames limestone. Near the north line of section 30 the Ames limestone was found exposed four feet and the top was 119 feet above the track at Brilliant Station. This shows a fall of thirteen feet in a s. s. w. direction in about one and one-third miles.

Smithfield Township gives the best showing of the Pittsburgh coal to be found in the county. Owing to the fact that the strata and the streams rise in the same direction and at very nearly the same rate, the streams rising a little the faster, the coal is available in all parts of the township. A comparatively small part of the coal has been eroded as the streams flow in deep, narrow valleys. Piney Fork of Short Creek flows through the township in an almost straight line from the northwest to the southeast corner, and cuts the coal throughout the township. At the northwest corner the coal is about thirty to forty feet above the stream, and at the southeast about 100 feet above it. The hills rise from 200 to 250 feet above the coal, thus giving plenty of cover, and as the sides are steep, little crop coal.

At the south side of section 33, on Russel's land, the coal gives the following section:

Roof shale		
Roof coal	2–4 inches.	
Clay, etc	10 "	
Bone coal	2 "	
Coal	28 "	
Slate parting	2 "	
Coal	15 "	4 ft. 6 in.
Parting	½ inch.	
Coal	9 inches.	
Clay		

On Newlin's land, S. W. quarter section 29, the coal measured as follows:

Shale	
Roof coal	18 inches.
Clay	12 "
Coal	27 "
Slate parting	2 "
Coal	10 "
Thin parting	
Coal	20 inches.
Clay—not measured	

MAP
OF
PITTSBURGH COAL
IN
JEFFERSON, BELMONT & GUERNSEY
COUNTIES.

OHIO GEOLOGICAL SURVEY
VOL. VI.

EDWARD ORTON, STATE GEOLOGIST.

By C. N. Brown.

M. R. Campbell, Del.

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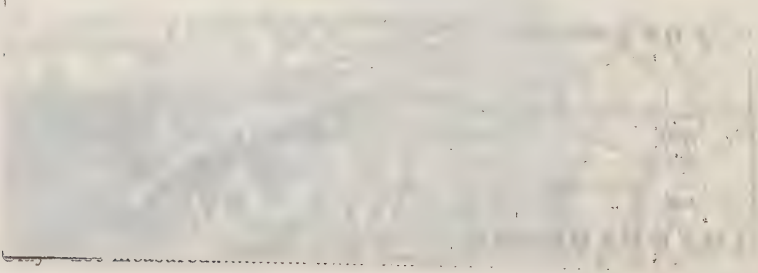


In N. E. quarter section 28, two coal blossoms were noticed above the Pittsburgh coal, one twenty-two feet and the other 101 feet above the bottom of the coal. There may have been another between these two, but it was not well marked.

In S. W. quarter section 10, the following section was measured with the hand-level, the figures indicating heights above the bottom of the Pittsburgh seam:

Coal, 18 inches, well shown	85	feet.
Clay shale	70–85	"
Black shale, thin	70	"
Shales { Clay, Calcareous..., Sandy, etc ... }	44–70	"
Limestone	37–44	"
Clay shale	25–37	"
Unseen	9–25	"
Top of roof coal	9	"
Bottom of main seam	...	

In S. W. quarter section 15, a coal twelve inches thick was found by the hand-level to be twenty-nine feet above the bottom of the Pittsburgh coal. No coal blossoms were noticed above this, although the conditions of the place were favorable for exposures.

In N. W. quarter section 22, the following section was obtained:

Shale	...	
Roof coal	24	inches.
Shale or clay	8–12	"
Coal	27	"
Clay parting, thin	...	
Coal	2	"
Slate parting, thin	...	
Coal	14	"
Thin parting	...	"
Coal	12½	"
Clay	...	

4 feet 8½ inches.

In N. E. quarter section 22, on H. G. Finley's land, at an old mine, the following section was measured:

Shale, clay and sandy	10	feet, exposed.
Coal	25	inches.
Clay, thin	...	
Limestone	2	feet.
Clay shale	11	"
Roof coal	30	inches.
Slate	2	"
Coal	8	"
Clay or soapstone	12	"
Black slate	1	inch.

Coal	28 inches.	
Parting	¼ inch.	
Coal	1½ inches.	
Parting	½ inch.	4 feet 10 inches.
Coal	15 inches.	
Slate parting	¼ inch.	
Coal	12 inches.	
Clay	...	
Limestone	...	

A little pyrites was noticed, most of which was gathered at the parting twelve inches from the bottom. This mine has been open for fifty-seven or fifty-eight years, and although in a very bad place and very poorly cared for, the roof, as far as examined, showed no signs of giving away. Many of the rooms are twenty-five to thirty feet span, and the posts have rotted away, yet the roof remains perfect.

The coal is mined near the centre of section 11, by means of a shallow shaft; it is for the market at Smithfield. It has the usual thickness and partings. The coal is opened on McIntire Creek, in the northeast corner of the township, where its thickness is reported about four feet six inches.

At Adena is one of the finest showings of the Ames limestone to be found in this part of the county. The stone is two to four feet thick, and paves the bed of the North Fork of Short Creek at its mouth. It is of light-gray color, and is highly fossiliferous. At this place the interval between the Ames limestone, and the Pittsburgh coal is almost entirely filled with sandy shales. The Ames limestone is not found again down Short Creek within this township.

Mt. Pleasant Township.—The surface of this township lies very high, as it makes the dividing ridge between the waters of Short Creek on the north and Little Short Creek and Wheeling Creek on the south. The only place where the Pittsburgh coal crops out is in the northern row of sections along Short Creek and its branches, the largest of which is Long Run. In the southern edge of the township the coal can be reached by shallow shafts in the valleys of the branches of Little Short Creek and Wheeling Creek. Where the coal shows on Short Creek and Long Run it is reported as five to five and one-half feet thick. At several points the double parting near the centre has been replaced by a single thin parting. In this way from four to six inches of good coal have been added to the top bench. The two lower benches and the lower parting make the same showing as they do farther north. The roof coal varies from six to eighteen inches, and is separated from the main seam by soapstone from ten to eighteen inches thick. Fragments of the Ames limestone were found along the bed of Short Creek, but its horizon could not be found. It is probable that it lies a little below the bed

of the creek, and that the fragments have been washed out by the water flowing over the mill-dams which have been built across the creek at various points.

Warren Township.—There is a large area of the Pittsburgh coal in this township, but it lies very high in the hills. The Ames limestone lies above the beds of all the larger streams in the township, except the western edge and southwest corner.

In S. W. quarter section 28, the coal gives the following section:

Roof coal	24–30	inches.	
Clay	4	"	
Coal	26	"	
Clay parting	1	inch.	
Coal	2	inches.	
Black slate parting	½	inch 1 foot.	4 feet 11 inches.
Coal	15	inches.	
Thin parting	...	"	
Coal	14	"	
Clay	4	"	
Limestone (not measured)	...		

The total of four feet eleven inches, it will be observed, is without the roof coal, which is also taken out in some places. This, if added, would make the vein about seven feet thick. In section 13 the coal was reported four-and-a-half to five feet thick, with the usual parting and roof. In section 18 thick beds of limestone were noticed, both above and below the coal. That above the coal sometimes reaches a thickness of forty feet. It has been used as a furnace flux. At Yorkville, in S. E. quarter section 22, the Pittsburgh coal is worked and shipped on the C. & P. R. R. The coal is from five to five-and-a-half feet thick. The bottom of the coal is here 192 feet above the C. & P. R. R. track at Yorkville. On Stringer's land, in N. W. quarter section 16, the bottom of the coal is 212½ feet above the C. & P. R. R. track at Tiltonville Station. At Chris. Wurwhol's, in N. W. quarter section 12, the coal is reported four-and-a-half feet thick, and the bottom is 272 feet above the C. & P. R. R. track at Portland Station.

The following section of a fossiliferous limestone was taken at the same place:

Sandstone (exposed)	20 feet.
Brecciated limestone	18 inches.
Coal	2 "
Laminated sandstone	12 feet.
Clay shale	5 "
Fossiliferous limestone	10 inches.
Blue and red-clay shale (exposed)	10 feet.

The fossiliferous limestone is 197½ feet below the bottom of the No. 8 coal, and 74 7/6 feet above the C. & P. R. R. track at Portland Station. The 10 inch limestone is highly fossiliferous, being filled with crinoid stems, brachiopods, etc. The limestone, which is eighteen feet higher and eighteen inches thick, is very sandy, and seems to be a conglomerate. No fossils were found in it. The interval between the limestone and coal was first measured with the hand-level as 197 feet, and afterwards with the engineer's Y level, which showed it to be 197.5 feet. This shows very well the kind of work that can be done with this small but extremely useful little instrument. At Kelley's mine, S. W. quarter section 7, the bottom of the coal is 287 feet above the C. & P. R. R. track opposite the mine. The coal is reported four and one-half to five feet thick, and is mined for shipment on the C. & P. R. R. On Little Rush Run, on John Lytton's land in S. E. quarter section 8, the bottom of the coal is 297 feet above the C. & P. R. R. track at Rush Run Station. On Peck's land, in S. W. quarter section 8, the Ames limestone was found sixteen to eighteen inches thick and eighty-four feet above the track at Rush Run Station. Another limestone, blue, slightly fossiliferous and very impure, is found at an elevation of fifty-seven feet above the track at the same point. Under this limestone is a faint coal-mark under which is a bed of fire-clay which has been worked. The upper limestone of these two is then 213 feet below the Pittsburgh coal, and the lower is 240 feet below it. As the C.&P.R.R. track is reported, by the chief engineer of the road, to be level between Yorkville and Rush Run Station, we may refer all the elevations to that level. We then have the coal at the following elevations:

In S. E. quarter	section	8	.....	297 feet.
In S. W. "	"	7	.....	287 "
In N. W. "	"	12	.....	272 "
In N. W. "	"	16	.....	212½ "
In S. E. "	"	22	.....	192 "

These points are on an almost straight line, the point in N. W. quarter, section 12, departing only about one-fourth mile east from the line joining the most northern and the most southern points. The distance between those extreme points is about 4.1 miles, and its direction is about S. 26° W. In going south from the most northern point, a fall of ten feet is observed in the first mile. From this point in S.W. quarter section 7, to the most southern part of Yorkville, there is a regular dip of thirty feet to the mile.

Belmont County.

Pease Township.—The Pittsburgh coal outcrops in the northwest corner of this township along Little Short Creek. It dips under the creek in center of section 3, where it is from four feet nine inches to five feet three inches thick. The clay between the main coal and the roof coal is very thin. The roof coal is from two to two and one-ha f feet thick, and is very good coal. The coal shows all along the river front and Wheeling Creek, in the southern part of the township, and is mined at many points along the river and creek, both for shipment and for use in the neighboring mills and factories. In the northern part of section 27, the coal measured from five to five and one-half feet thick. The clay between the roof coal and the main coal is only two to four feet thick. The middle parting has been reduced to one thin slate band of one inch. The bottom parting was not observed. The section is as follows:

Roof coal (not measured)	
Clay	2–4 inches.
Coal	24–36 inches.
Slate	1 inch.
Coal	30–36 inches.
Clay	6–9 "
Limestone (not measured)	

The total of coal between the two clays is five to five and one-half feet.

In S. W. quarter section 25, on Glenn's Run, the following section was taken:

Coal blossom	
Limestone, with thin clay beds through it	12–15 feet.
Clay shale	8 feet.
Roof coal	20–24 inches.
Clay	20–22 "
Total coal	5½ feet.
Clay	6 inches.
Limestone and clay (exposed)	6 feet.

A double clay parting, enclosing a thin coal, is found thirty-six inches from the bottom. The lower parting does not show.

On John Schrack's land, in the southern part of the township, the following section is given:

Limestone	
Shale	8–10 feet.
Roof coal	2½–3 feet
Slate	9 inches.
Coal	29 "

Slate parting	½ inch.
Coal	3 inches.
Slate parting	½–1 "
Coal	33 "
Clay	1–2 feet.
Limestone	———

The total coal is five feet six inches. The lower parting is not shown in this section. The bearing-in is made in the central double parting.

At the Wheeling Creek mine in section 3, the following section was taken in a ventilating shaft:

Limestone	12 feet.
Clay	4 "
Coal	6 inches.
Clay	1 foot.
Clay and shale	2 feet.
Limestone (bedded)	16 "
Limestone (nodular)	3 "
Clay	2½–3 feet.
Black slate	2–3 inches.
Roof coal (varying 8–18 inches)	12 "
Clay (varying 0–18 inches)	10 "
Coal	30 "
Parting	0–1 inch.
Coal	4 inches.
Parting	0–½ idch.
Coal	8 inches.
Parting (thin)	———
Coal	8 inches.
Parting (thin)	———
Coal	15 inches
Limestone	4 "
Clay	———

The coal varies from five to six feet in thickness. At the Wheeling Creek mines Mr. W. B. Hanlon, C. E., measured a dip of twelve feet in a distance of 4,800 feet from north to south, and eight feet in a distance of 4,000 feet from west to east. The greatest dip, therefore, is seventeen feet per mile, in a direction S. 38° E. In this mine a fault was found running in a N. E. and S. W. direction. The coal was cut almost squarely, and on the southeast side the bottom of the coal was level with the top of the coal on the northwest side, thus giving a displacement of about six feet. The same fault has been found in the mines back of Bridgeport, and on the river-front just below Martin's Ferry, and it is claimed to have been found in the mines on the Virginia side of the Ohio River above Wheeling. To the southwest it has been found in the mines at Quincy Station, on the B. & O. R. R., in Pultney township. South of that it has not been noticed.

The Wheeling Creek mines put out more coal and are better arranged for handling a large quantity than any other mines in this vicinity. The works can load, if necessary, from eighty to ninety cars per day. At the time visited—the summer of 1886—they were shipping fifty to sixty car loads of lump coal per day. The coal is creened over a 1⅜-inch screen. From one-third to two-fifths of the coal goes through it, making one car of nut coal to about six of lump, and one of slack and dirt to about four of lump. The bearing-in is made at or near the bottom and the coal is then shot down. Considerable care must be taken to pick out all the black slate of the central parting, or the market value of the coal is seriously injured. The coal is rather tender, and must be shot very lightly to make large coal. Twelve coke ovens at the mines work a part of the slack into coke. There is not market for the entire quantity that could be made, as the coke has too much sulphur for iron-making.

The composition of the coal from these mines is as follows: (*Lord*)

Moisture	1.74
Volatile combustible matter	41.39
Fixed carbon	48.90
Ash	7.97
Sulphur	4.12

In S. E. quarter section 27, the bottom of the Pittsburgh coal is seventy-six feet above the C. & P. R. R. track at Bridgeport. In Heinlein Brothers' bank in the center of the east side of section 28, the bottom of the coal is ninety-one feet above the C. & P. R. R. track at Bridgeport. At the Laughlin Mill mine at Martin's Ferry in S. E. quarter section 24, the bottom of the coal is 122 feet above the C. & P. R. R. track at Bridgeport, and 121 feet above that track at Martin's Ferry. At Rainey's mine in N. W. quarter section 9, the bottom of the coal is 125 feet above the C. & P. track at Bridgeport and 121 feet above the track at Rainey Station. These elevations give a dip of three feet in 1½ miles, or two feet per mile due south, from Rainey's to Laughlin Mill mine. From Laughlin Mill mine to Heinlein Bros.' bank about S. 40° W. about 2¼ miles, is a dip of thirty-one feet or about 13.8 feet per mile. From Heinlein Bros.' mine to Rhoades' mine in S. E. quarter section 27, the distance being about one mile due south, the dip is fifteen feet. In N. W. quarter section 9, near Burley's Mill, the coal is about 145 feet above the C. & P. track at Bridgeport. This is almost due west of the Rhoades mine and about 3¼ miles distant. This gives a dip to the east of sixty-nine feet in 3¼ miles, or about twenty-one feet per mile.

The composition of Rainey's coal is as follows:

Moisture	2.05
Volatile combustible matter	40.41
Fixed carbon	50.51
Ash	7.99
Sulphur	4.20
Specific gravity	1.354

Colerain Township.—This township has the Pittsburgh coal cropping all along Wheeling Creek and its branches through the southern and western parts of the township. The coal does not come to the surface in the northern part, but it can be reached by shafts very few feet deep in the valley of Little Short Creek, in the northeast corner of the township. There are several large mines that ship coal on the C. L., & W. R. R. to the north and northwest. The mines at Maynard, in N. W. quarter section 31, owned by the same company as the Wheeling Creek mine in Pease township, Kidd's mine, in N. W. quarter section 25, and a mine at Barton Station, in N. W. quarter section 24, are the largest of these mines. The Maynard mines are the largest and best arranged, and have a capacity of forty to fifty cars of lump coal per day. At these mines the coal measured as follows:

Roof coal	about 18 inches
Soapstone	2–15 "
Bone coal	3 "
Coal	18 "
Bearing-in place { Slate parting / Coal / Slate parting }	7 inches.
Coal	18 "
Very thin parting	⅛ inch.
Coal	12 inches.
Clay (exposed)	8 "

In the Maynard mines no clay-veins nor horsebacks have been found yet. Two small faults have been discovered, the larger showing a displacement of from two to three feet.

The composition of this coal is as follows: (*Lord*)

Moisture	2.46
Volatile combustible matter	39.36
Fixed carbon	50.91
Ash	7.27
Sulphur	2.89

At Kidd's mine, in N. W. quarter section 25, the coal gives the following section:

Clay shale (not measured)	———
Roof coal	12–18 inches.
Soapstone	12 "
Bone coal	2 "
Coal	36 "
Slate / Coal / Slate	3 "
Coal	27 "
Thin parting	⅛ inch.
Coal	4 inches.
Hard slate	12 "
Limestone	18 "
Soapstone	6 "
Limestone (exposed)	18 "

The analysis of this coal is as follows: (*Lord*)

Moisture	1.93
Volatile combustible matter	39.64
Fixed carbon	50.58
Ash	7.80
Sulphur	3.97
Specific gravity	1.316

In S. W. quarter section 19, a section below the coal was taken as follows:

No. 8 coal	5–6 feet.
Clay	1–2 "
Limestone	3 "
Soft clay shale	10–12 "
Thin layers of limestone and shale	2 "
Shale	9 "
Limestone	4 "
Shale (to creek bed)	6 "

This section under the coal is replaced in sections 10 and 16, in the southern part of the township, by a massive sandstone that comes up close to the coal.

Wheeling Township.—The Pittsburgh coal is exposed along Wheeling Creek from the eastern edge to the center of the township, where it disappears under the creek. It is exposed along Crab Apple Creek, a branch of Wheeling Creek, from the southern edge of the township almost to the north line of the township and of the county. On Cox's Run, in the eastern row of sections, the coal has its usual thickness of

five to five and one-half feet, and the roof coal and the central band of slate and thin coal all regular.

In S. E. quarter section 19, on Patten's land, the bottom of the coal is level with the C., L. & W. R. R. track. About three-fourths of a mile southwest of this point, up the creek, the top of the coal is below the usual level of Wheeling Creek, and the bottom is from fifteen to eighteen feet below the C., L. & W. R. R. track at that point; one-half mile west of this place, on the boundary line between sections 24 and 30, the bottom of the coal is again level with the C., L. & W. R. R. track at that point. In the center of section 30 it disappears, not to be seen again east of the divide at Flushing. Going up Crab Apple Creek, at its confluence with Wheeling Creek, in section 24, the coal is found but a few feet above the bottom of the valley, but it rises almost as fast as the stream and does not go under drainage until it reaches N. quarter section 27.

Near the center of section 25 the following section was taken at a small mine worked to supply the local market:

Thick, solid bed of limestone (exposed)	5 feet.
Shale	12–15 "
Roof coal (average)	12 inches.
Clay (average)	14 "
Coal	24–30 "
Bearing-in place { Clay shale / Coal / Clay shale }	4–6 "
Coal	30–33 "
Clay (not measured)	

The total vein ranges from five to five and one-half feet.

At Wm M. Campbell's mine in N. E. quarter section 26, the coal gave a somewhat unusual section, as follows:

Roof coal (not measured)	
Slate	12 inches.
Coal	6 "
Slate parting	1–1½ "
Coal	12 "
Slate / Coal / Slate	6 "
Coal	35–36 "
Clay	12 "
Limestone (not measured)	

Numerous reports of a vein of ten to twelve feet of coal on the upper part of Crab Apple Creek were heard at different places, but on investigation of them and examination of the locality where this

mammoth vein was said to be, nothing of the kind could be found, but only the usual five to five and one-half feet of good coal and the roof-coal.

Flushing Township.—The Pittsburgh coal crops out in the bed of Stillwater Creek in sections 25 and 26, one mile southwest of Flushing Town. As the coal rises to the west and the creeks flow in the same direction, the coal soon reaches the tops of the high hills and ridges. It is not found in the extreme western part of the township, except as small unimportant outliers.

At Jos. Butler's mine, in S. W. quarter section 26, about one mile west of Flushing Station, on the C., L. & W. R. R., the coal is mined for shipment by rail. It there gives the following section:

Soapstone or clay shale	
Poor, slaty coal	3 inches.
Bone coal or black slate	9–12 inches.
Coal	22 "
Slaty coal	2–4 "
Coal	22 "
Slate or clay parting	1–1½ "
Coal	12 "
Clay	14 "
Limestone (not measured)	

The total coal is from four feet nine inches to five feet two inches. A part of the slack from this mine was formerly made into coke, but the work has been discontinued.

The analysis of the seam at this point is as follows: (*Lord*)

Moisture	2.76
Volatile combustible matter	40.85
Fixed carbon	48.92
Ash	7.47
Sulphur	3.24
Specific gravity	1.326

The analysis of the coke is as follows:

Ash	17.74
Sulphur	3.57

In N. E. quarter N. W. quarter section 8, the following section was taken:

Massive ledge of sandstone (not measured)	
Coal	10 inches.
Clay or slate parting	½–1 inch.
Coal	3 inches.
Slate parting, thin	¼–½ inch.
Coal	29 inches.
Clay	30 "
Limestone	

This section shows the roof coal, the soapstone under it, and a part of the top bench of the main coal cut away and replaced by a coarse sandstone. The eastern edge of this cut-out is a short distance west of Rock Hill. The sandstone is well shown in the top of the ridge extending northwest from Rock Hill and seems to thicken to the west, reaching a thickness of from twenty to twenty-five feet.

The Ames limestone was found nicely shown in S. W. quarter section 14, along Big Stillwater. It is here from two to two and a half feet thick, solid, dark-colored, full of fossils and bedded in a fossiliferous, calcareous clay shale, which extends several feet both above and below it. The limestone was found at many points along the Big Stillwater, and also along the branch that is followed by the C., L. & W. R. R., as far up as Holloway Station.

The Meigs Creek coal was a few years ago mined at Flushing Station for shipment on the C., L. & W. R. R., but it has been almost, if not quite, abandoned, as it could not compete with the No. 8 coal in the market, and was but three feet three inches to four feet two inches thick.

The analysis of this seam at this point is as follows: (*Lord*)

Moisture	3.18
Volatile combustible matter	38 31
Fixed carbon	50.10
Ash	8.41
Sulphur	1.78
Specific gravity	1.30

Kirkwood Township.—This township holds a considerable area of the coal, but in the northern and western parts it is high in the hills, and badly cut up by the drainage.

At Hendrysburgh, on John McCartney's land, in S. W. quarter N. E. quarter section 20, the following section was taken:

Hard shaly sandstone	——	
Clay shale	4– 6	inches.
Roof coal	12	"
Shale, top clay, bottom black	17–18	"
Coal	18	"
Parting, mostly pyrites	½– 2	"
Coal	2– 3	"
Very thin slate parting but well marked	⅛	inch.
Coal, best of the vein	22	inches.
Thin, black slate, bearing-in place	⅛– ½	inch.
Coal	14	inches.
Clay or clay shale	6– 9	"
Limestone	1	inch.

The shale between the main coal and roof coal here affords a good and safe roof, and hence is not taken down as the coal is gained. It will be noticed that here the sandstone is not quite down to the coal, as it is farther north and west In section 7, along the pike, the limestone ledge a few feet above the coal was noticed in its usual place and thickness. In N. W. quarter section 28, a massive sandstone, from fifteen to twenty feet thick, forms the roof of the coal, but does not cut down into it. The sandstone makes a good building stone, works well, does not weather badly, and can be had in blocks of any desired size. In E. half of section 23, in the limestone, a few feet above the coal, a large quantity of flint was observed imbedded in it. It was of black and reddish brown colors, and, as far as examined, was like the limestone, non-fossiliferous.

In S. W. quarter S. W. quarter section 29, at Wm. Lightell's mine, the following section was measured:

Massive sandstone (exposed)	22	feet.
Black slate	1	inch.
Slaty coal, taken out and used	4	inches.
Coal	12	"
Slate parting, much pyrites	½–2	"
Coal	3	"
Thin slate parting	⅛–¼	inch.
Coal	18	inches.
Slate parting	0–1	inch.
Coal	14½	inches.
Clay	2–8	"
Limestone		

The bearing-in is made on top of the lowest parting. The faces run almost due east and west. In some parts of the mine six inches to eighteen inches of soapstone are found between the main coal and the sandstone, and in some places bits of coal are mixed with the top of the soapstone, but no regular roof coal has ever been found.

In the hill above this mine the following section was measured showing the position of two other coals, the figures indicating height above the bottom of the Pittsburgh coal:

Pittsburgh coal, 4 feet to 4½ feet thick		
Massive sandstone exposed from top of coal to	28	feet.
Strong coal mark 1½ feet to 2 feet thick	62	"
Coal 4 feet thick, the bottom being at	98	"
Top of hill about	150	"

This mine and the section are in the north end of the village of Sewellsville.

In the southwest corner of the township about Fairview, the coal is from four to four and a half feet thick, and has the sandstone roof.

Union Township.—The crop of the coal occurs in the western edge of the township only, being at only one point as far as two miles from the western line of the township. In E. half of section 36, at the head of Six-mile Run, the coal was reported as follows :

Shale roof, poor	——
Roof coal	8–10 inches.
Soapstone	4–9 "
Coal with thin parting near centre	3 ft. 9 inches to 4 feet.
Clay	2–6 "
Limestone	——

The coal as reported is somewhat thinner than usual, and the central parting is not well defined. The roof coal is taken out and used with the other coal.

The coal has been mined for local use near the centre of section 31. It is reported that the coal is here thirteen feet thick. When the mine was visited, it could not be entered nor examined satisfactorily. The main coal and the part mined are from five to six feet thick. But a few inches of soapstone separate the main coal from the roof coal, which appears to be of better quality and greater thickness than usual. This may be the reason for the report of a mammoth coal vein. If it is as thick as reported, it is due only to a local thickening of the roof coal and to a thinning out of the soapstone.

The bed of limestone a few feet above the coal holds in all the exposures through the township. Just west of Morristown a coal above the No. 8, probably the Meigs Creek coal, is worked more than the No. 8 for local use. The upper coal has a better roof than the No. 8, but is reported to be not quite as good a coal.

Richland Township.—This large township is mostly highland, and shows but little outcrop of the coal. It crops on Jug Run in section 6, in the northern part along Wheeling Creek, for about $1\frac{1}{2}$ miles in the northeast corner, in section 19, for a short distance along the railroad from St. Clairsville to Quincy Station, and for about 3 miles along the B. & O. R. R. and McMahan's Creek in the southeast corner. On Jug Run the coal is reported as five and one-half feet thick, and with the usual roof coal and partings as found along Wheeling Creek in Colerain township. Along Wheeling Creek in sections 22 and 23, the coal has the usual structure and thickness. It is here underlaid with a massive sandstone, as further down the Creek in Colerain and Pease townships. The sandstone replaces the clay shale and limestones usually found for twenty to thirty feet under the coal. On McMahan's Creek, in the southeast of the township, the coal is but a few feet above drainage, and finally disappears under the creek in S. E. quarter section 35, about $\frac{3}{4}$

mile east of Glencoe Station, B. & O. R. R. The coal shows its structure and thickness in the tunnel west of and the cut east of Franklin Station. It varies from five to five and one-half feet in thickness, and has the roof coal and soapstone above and the regular partings near the centre and bottom. The roof coal is about one and one-half feet thick and has a 3-inch parting near the top. Over it is a bed of limestone and clay shale exposed for a thickness of about twenty feet. The coal is mined for shipment on the B. & O. R. R. at Franklin Station.

Pultney Township.—In this township the Pittsburgh seam has been worked more largely than in any other township of the coal-field. It has been worked for over forty years about Bellaire, and is frequently known as the Bellaire coal. It has been worked along the B. & O. R. R. for use and shipment on that road, almost ever since its completion. At Bellaire it is worked for domestic uses, for use in the numerous glass and iron works at that place, and for use of steamboats and for shipment down the Ohio River to southern markets.

The coal is very regular in its thickness, varying from five to six feet, five and one-half feet being a fair average of the main coal under the soapstone and roof coal. In the northern part of the township, on the river front, the coal is 108 feet above the C. & P. R. R. track, and at the southern edge it is down to low water in the Ohio river. At the mines of Rockershousen and Sterritt, in S. W. quarter section 28, the coal gives the following section:

Roof coal and black slate	3–5 feet.
Clay	9 inches.
Coal	25 "
Clay	1 inch.
Coal	4 inches.
Black slate	1 inch.
Coal	18 inches.
Black slate	½–1 inch.
Good coal	13 inches.
Rone coal	4 "
Limestone (not measured)	

The coal at this mine is reached by a slope, being almost level with the bed of the Ohio River.

At Heatherington's mine for the glass works, the coal measured as follows:

Shale and limestone (not measured)		
Roof coal	Coal	12 inches.
	Black slate	4 "
	Coal	12 "
Clay		10 "
Coal		30 "

Slate Coal Slate	5	inches.
Coal	21	"
Black slate and pyrites	½	inch.
Coal	12	inches.
Hard, slaty coal	4	"
Clay (not measured)		

The roof coal is not taken out. The clay between the roof coal and main coal comes down with, or soon after the coal, and makes it dangerous to work under it. The mines here have been worked for many years for use on the river and at the glass works. All the coal has been taken from under the front range of hills, and the workings are now under the second range, more than a mile from the mouth of the entry. The roof coal makes a good, strong roof. The ribs left between the rooms are but six feet thick, and are drawn when the rooms have been worked out. The main coal at one place measured five feet eleven inches in thickness.

The composition of Heatherington's coal is shown below: (*Lord*)

Moisture	1.53
Volatile combustible matter	42.29
Fixed carbon	47.57
Ash	8.61
Sulphur	4.47

The analysis of the roof coal is also appended: (*Lord*)

Moisture	1.93
Volatile combustible matter	40.54
Fixed carbon	45.80
Ash	11.73
Sulphur	6.33
Specific gravity	1.356

At W. G. Barnard's mine, in the northern part of Bellaire, the coal measures as follows:

Roof coal	24–30	inches.
Soapstone (average)	12	"
Coal	24	"
Slate	1	inch.
Coal	4	inches.
Slate	1	inch.
Coal	18	inches.
Slate	¼–½	inch.
Coal	13	inches.
Thin parting, often pyrites	⅛–¼	inch.
Coal	3	inches
Hard, sandy rock and pyrites	3	"
Clay	3	"
Limestone		

The middle bench of eighteen inches is often saved by itself and shipped west for gas-making. It is a good gas coal, as it is very free from sulphur. The soapstone between the roof coal and main coal in spots reaches a thickness of four feet, and at Kidd's mine, at Quincy Station, on the B. & O. R. R., averages about five and one-half feet in thickness. The roof coal is usually thin, not often over twelve inches. The clay between the two coals is full of slickensides and has to be taken down as fast as the coal is removed from under it. At this mine is found the prolongation of the fault that was noticed in the Wheeling Creek mines in Pease township. Another small fault, showing a displacement of one and one-half to two feet, has also been found. A clay vein of about six feet in thickness has been cut through in this mine. Horsebacks and clay veins are very seldom found in this township in the coal, but its regularity in thickness and structure is very remarkable.

The analysis of Barnard's coal is as follows: (*Lord*)

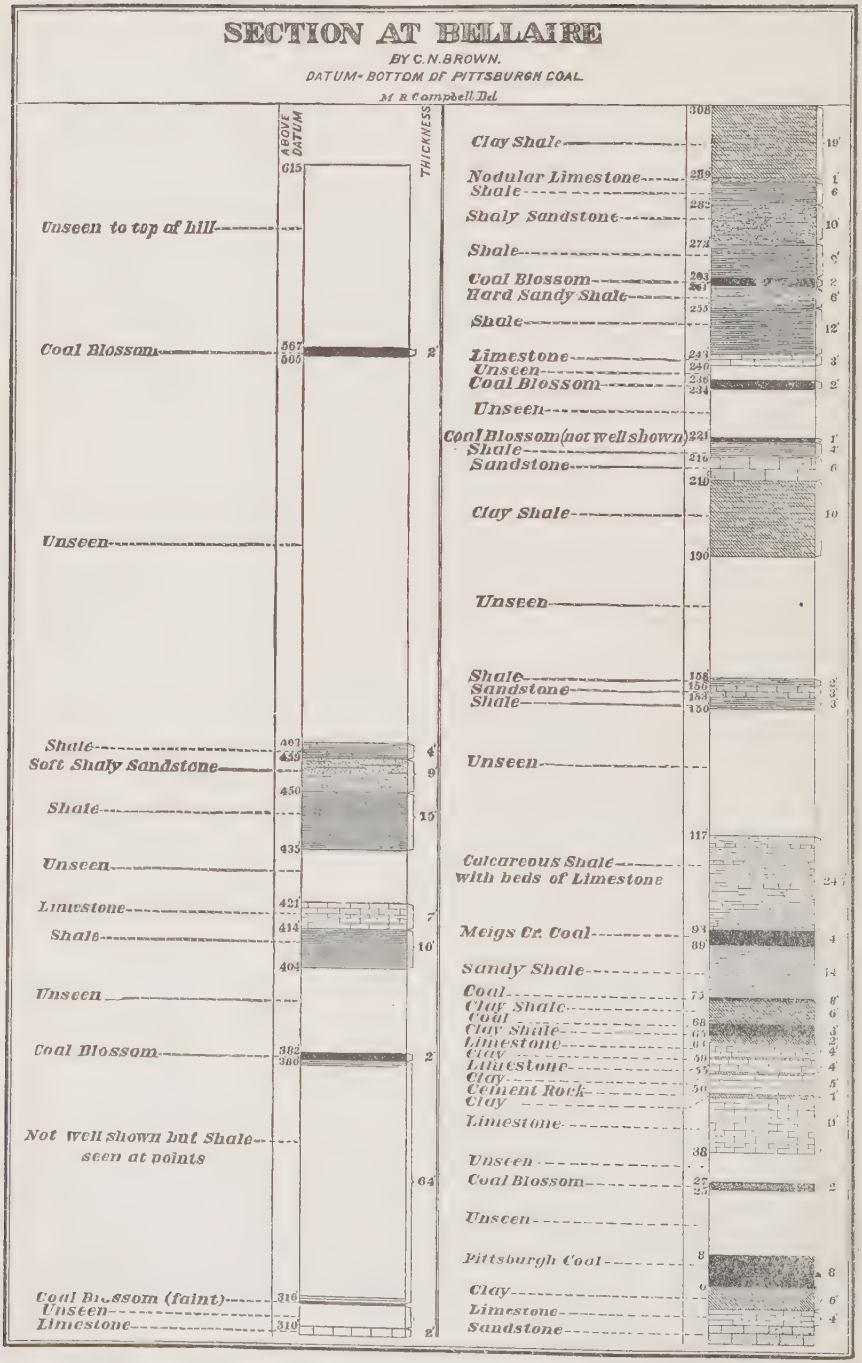
Moisture	1.87
Volatile combustible matter	40.76
Fixed carbon	50.11
Ash	7.27
Sulphur	4.13
Specific gravity	1.312

The coal of the Pittsburgh works mined within the town limits is given herewith:

Moisture	1.52
Volatile combustible matter	41.70
Fixed carbon	48.69
Ash	8.09
Sulphur	4.98
Specific gravity	1.304

In the south end of Bellaire, in S. W. quarter section 29, the following section, showing the strata above the Pittsburgh coal, was measured with the hand-level, the distance from the bottom of the coal being given:

Top of roof coal	7–8	feet.
Unseen	8–25	"
Coal blossom	25–27	"
Unseen	27–38	"
Limestone	38–49	"
Clay seam	49–50	"
Cement rock	50–55	"
Thin clay seam	55	"
Limestone	55–59	"
Thin clay seam	59	"


SECTION AT BELLAIRE
BY C. N. BROWN.
DATUM- BOTTOM OF PITTSBURGH COAL.
M. R. Campbell, Del.
ABOVE DATUM
THICKNESS
615
Unseen to top of hill
567
560
Coal Blossom
2'
Unseen
467
459
Shale
4'
Soft Shaly Sandstone
9'
450
Shale
10'
435
Unseen
421
Limestone
7'
414
Shale
10'
404
Unseen
382
380
Coal Blossom
2'
Not well shown but Shale seen at points
64'
316
Coal Blossom (faint)
Unseen
Limestone
310
2'
308
Clay Shale
19'
Nodular Limestone
Shale
1'
6'
Shaly Sandstone
10'
Shale
Coal Blossom
Hard Sandy Shale
Shale
12'
Limestone
Unseen
Coal Blossom
Unseen
Coal Blossom (not well shown)
Shale
Sandstone
Clay Shale
10'
190
Unseen
158
156
153
150
Shale
Sandstone
Shale
Unseen
117
Calcareous Shale with beds of Limestone
24'
93
89
Meigs Cr. Coal
4'
Sandy Shale
14'
75
Coal
Clay Shale
Coal
Clay Shale
Limestone
Clay
Limestone
Clay
Cement Rock
Clay
Limestone
38
Unseen
Coal Blossom
27
25
2'
Unseen
Pittsburgh Coal
8'
0
Clay
Limestone
Sandstone

Limestone	59–63 feet.
Clay shale	63–65 "
Coal (See section of coal below)	65–68 "
Clay shale	68–74 "
Coal	74–74 " 8 in.
Sandy shale	74 ft. 8 in.–88 ft. 6 in.
Coal	88 " 6 " 92 " 6 "
Calcareous shale with thin beds of limestone	92 " 6 " 117 "
Unseen	117–150 feet.
Shale	150–153 "
Sandstone	153–156 "
Shale	156–158 "
Unseen	158–190 "
Clay shale	190–210 "
Sandstone	210–216 "
Shale	216–220 "
Coal blossoms, not well marked	220–221 "
Unseen	221–235 "
Coal blossoms, strong, well marked	235 "
Unseen	235–240 "
Limestone	240–243 "
Shale	243–255 "
Hard, sandy shale	255–261 "
Coal blossom, well shown	261–263 "
Shale	263–272 "
Shaly sandstone	272–282 "
Shale	282–288 "
Nodular limestone	288–289 "
Clay shale	289–308 "
Limestone	308–310 "
Unseen	310–316 "
Coal blossom, not well shown	316 "
Not well shown, but looking like shale mostly	316–380 "
Coal blossoms, well shown	380–382 "
Unseen	382–404 "
Shale	404–414 "
Limestone	414–421 "
Unseen	421–435 "
Shale	435–450 "
Soft shaly sandstone	450 459 "
Shale	459–463 "
Unseen	463–565 "
Coal blossom, strong, well shown	565–567 "
Unseen to top of hill	567–615 "

The section of the coal at sixty-five feet above the bottom of the Pittsburgh coal is as follows:

Clay shale, from 68 feet to 74 feet	6 feet.
Coal	4 inches.
Clay	6 "
Coal	3 "
Clay	2 "

Coal	11	inches.
Clay	5	"
Slaty coal	10	"
Clay shale, from 63 feet to 65 feet	2	feet.

Along McMahan's Creek back of Bellaire a coarse sandstone comes in close under the coal. In section 36 it is eleven feet below the coal and twenty-five feet thick. It makes a fair building stone for heavy masonry, such as foundations for houses, bridge abutments, piers, etc. It was used for the piers of the B. & O. R. R. bridge over the Ohio River at Bellaire. By taking the elevations of the coal in section 18 at Neff's siding, in section 26 on the north line of the township, and at Rockershousen's mine in section 28 in the south edge of the township, the dip of the coal is found to be very nearly thirty feet per mile in a S. 37½° E. direction.

Mead Township.—The coal seam is mined at several points along the river in this township by means of slopes and shafts of moderate depth. It does not crop in the township. The coal is mostly shipped on the river and used on steamboats, a small portion being consumed in the local market for domestic uses. The coal is reported of the same thickness and structure as about Bellaire.

York Township.—Although this township is south of Mead, and is the most southeastern township of Belmont county, it shows a crop of the No. 8 coal on Captina Creek in sections 21 and 27, about three and one-half miles northwest of the village of Powhattan at the mouth of Captina Creek. The coal must change its dip very considerably from Mead and Pultney townships, in order to come to the surface again at this point. The coal is reported in the bed of the river opposite Powhattan.

On F. Dorsey's land, in N. W. quarter S. W. quarter section 14, M. C. Workman works a mine in the Pittsburgh coal for the local market. The coal is here reached by a shaft twenty-five feet deep. The coal and water are hoisted by horse-power. The section of the coal is as follows:

Roof coal (average)	20	inches.
Slate, 0–24 inches (average)	14	"
Coal	25	"
Slate and pyrites	½–2	"
Coal	6	"
Slate	0–1½	"
Coal	19	"
Pyrites band	1–2	"
Coal	10	"
Coal (a few inches not measured)	———	
Clay (not measured)	———	

The bottom coal is never raised, as it is poor and slaty, and when broken allows a large amount of water to come into the mine. The best coal of the seam is the top bench of twenty-five inches. The bearing-in is made in the bottom, and the coal is then shot in the central double-parting and thin coal. The faces of the coal are east and west as nearly as could be determined with a small compass. Neither clay veins, horsebacks nor faults have been found in this mine, but the coal rises gently and uniformly to the north.

The coal comes above the bed of Captina Creek, in S. E. quarter section 21, and remains only a few feet above the creek until reaching the S. W. quarter section 27, when it again goes under the creek-bed. The coal has been opened in several places, and is often laid bare in the creek bluffs. The mines are all liable to be flooded by high water from Captina Creek.

In S. E. quarter section 27, a section was taken with the barometer showing five coals above the Pittsburgh seam. None of them have been opened in this vicinity. The section is as follows, giving distances from the bottom of the No. 8 coal:

Thin coal over bed of limestone several feet thick	27	feet.
Coal, 3–4 inches over bed of limestone several feet thick	68	"
Coal blossom, well marked	96	"
" not well marked	288	"
" well shown	338	"

Washington Township.—The Pittsburgh coal does not crop in this township, but it is worked by means of a shaft in N. E. quarter section 10, on the B., Z. & C. R. R. The coal gives the following section:

Clay and clay shale (not measured)	
Roof coal	12 inches.
Clay	10–12 "
Coal	33 "
Slate	½ inch.
Coal	24 inches.
Slate	¼–½ inch.
Coal	14 inches.
Clay (not measured)	

The total of the main coal is six feet. This is about the average all through the mine. The coal is very uniform in thickness and structure, and no irregularities such as clay veins, horsebacks or faults have been found. The roof coal makes a good safe roof. The clay is taken down with the main coal.

This mine is troubled somewhat by the presence of fire-damp and oil. The oil is found mostly on one side of the mine, where it seeps out of the coal and roof and gathers on the water in the drains and sumps.

Enough is gathered to oil the small coal cars and machinery about the mines, and the remainder is pumped out with the water and turned into the creek. It has taken fire several times and so caused considerable trouble in working the mine. The amount of fire-damp is not large. After the mine has been examined in the morning by the mine boss with a safety lamp, the miners go in with their naked lights.

The shaft is seventy-four feet deep from the surface to the bottom of the coal. The strata passed through are alternate beds of limestone and clay shale. The four-foot coal that supplied local use before the shaft was opened, is here ninety-eight feet above the bottom of the Pittsburgh coal. The coal from the shaft is shipped and used on the narrow-gauge railroad running past the mine from Bellaire to Zanesville.

The composition of the coal is as follows: (*Lord*)

Moisture	1.55
Volatile combustible matter	42.47
Fixed carbon	47.70
Ash	8.28
Sulphur	5.14
Specific gravity	1.345

Goshen Township.—The Pittsburgh coal shows in but one place in this township. That is in N. W. quarter section 36. The coal is there stripped in the bed of the stream on Du Bois's land. No mines in the coal were found in the township. At Du Bois's place the coal is from four and one-half to five feet thick, with the usual partings. Where it was opened no roof coal was observed, but its place was taken by a bed of clay. The roof coal may have been eroded by the present water course. To the north of this exposure the bed of limestone a few feet above the coal was noticed in full force.

Warren Township.—This township shows the coal in the northern and western part. The eastern and southern part is high land, forming a part of the watershed between the Ohio and Muskingum rivers. In this township the Meigs Creek coal is worked almost if not quite as much as the Pittsburgh coal. About Barnesville the Meigs Creek coal is used almost entirely. The two coals are here of about the same quality and thickness, the Pittsburgh coal being cut down by the sandstone roof.

In sections 11 and 17 the Pittsburgh coal is reported about four feet thick, with no roof coal and a poor, weak shale roof, while the Meigs Creek coal is of about the same thickness, with a firm strong roof. In sections 12 and 17 the thick ledge of sandstone comes down on the coal, cutting away the roof coal and reducing the upper bench of the main coal. In the northwest corner of the township the coal is from four to four and

one-half feet thick, with the sandstone roof. It is here so filled with pyrites as to be almost useless, even for domestic and steam purposes.

The coal is worked in N. E. quarter section 31 for the use of the locomotives on the B. & O. R. R. It here gives the following section:

Shaly sandstone (not measured)	
Sandy shale	3½ feet.
Coal	13 inches.
Clay parting	1 inch.
Coal	26 inches.
Slate	½ inch.
Coal	14 inches.
Clay	6 "
Limestone (not measured)	

The coal all through the southwest part of the township has about the same section as that above given. The sandstone frequently rests immediately on the coal, and the quality is then usually poorer, there being more pyrites in the coal.

Somerset Township.—The Pittsburgh coal is found only in sections 30 and 36 of this township. It is reported to have the same thickness and structure as in the southwestern part of Warren township.

Guernsey County.

Millwood Township.—This township has a larger area of the Pittsburgh coal than any other township of Guernsey county. In the southeast corner, along the B. & O. R. R., the coal is about 130 to 140 feet above the track. At the west side of the township it is from 210 to 220 feet above the track and near the hill-tops. The high ridge and its spurs between Salt Fork of Wills Creek, in Oxford township, and Leatherwood Creek in this township, holds the coal throughout the township.

In N. E. quarter section 20, near Quaker City, on the land of Doudna and Bros. the coal is mined for local use. It here gives the following section:

Shale roof (not measured)	
Slaty coal, not good	3–4 inches.
Coal	10 "
Slate parting with pyrites	½–1-inch.
Coal	20 inches.
Clay parting	½ 1-inch.
Coal	16 inches.
Clay	

The total coal is about four feet. In this mine a few horsebacks have been found that cut down almost to the bottom of the coal.

The coal ranges about four feet throughout the township, and

usually has considerable pyrites scattered through the coal, as well as gathered at the upper parting. No trace of the roof coal was found. In many places in the township there is no shale between the coal and the sandstone that is shown over the shale in the last section. The quality of the coal is usually reported as poorer when the sandstone rests on it. At Quaker City the coal is 190 feet by the Y-level, above the Ames limestone, and at Salesville, in section 32, it is, by hand-level, 193 feet above the Ames limestone.

Oxford Township.—The principal area of the Pittsburgh coal in this township is in the ridge running east and west through the central part of the township, along which the national turnpike runs. There is a ridge in the southeast corner that holds the only other area of any size. There are small unimportant outliers in sections 9, 25, 27, 31 and 35, which are of little economic value, the coal in them having a light cover and being very poor and rotten. About Fairview, in the eastern part of the township, the coal is from thirty-eight to fifty inches thick, with a sandstone roof and no roof coal.

In N. W. quarter section 2, at Galbraith's bank, just west of Fairview, the coal measures as follows:

Shale, yellow } " black }	
Coal	12 inches.
Parting of clay or slate	4–5 "
Coal	15 "
Thin parting	
Coal	12 inches.
Fire-clay (exposed)	3 "

The best coal is found in the middle bench of fifteen inches. The bearing-in is made on the lower parting.

A coal near the place of No. 8*b* has been cut through in a well near this mine. It was reported as two feet thick and very slaty and poor. The interval could not be measured. At this mine the coal always dips to the west, at one place as much as eight feet in 100 feet. No roof coal was found either here or farther west. In the southeast corner of this township no sandstone was noticed over the coal, only clay shale. The marks of coals 8*a* and 8*b* were noticed at several points. The Ames limestone is exposed in section 6, but the interval to the No. 8 coal could not be measured with the hand-level. To the west of Fairview for a few miles a clay shale replaces the sandstone over the coal and marks of coals 8*a* and 8*b* were observed. The roof coal was not seen, but was reported in the outlier in sections 25 and 27 of a thickness of twelve inches and with twelve inches of clay between the main coal

and the roof coal. The coal was, years ago, worked in a shaft in S. E. quarter section 20, and is reported three and one-half feet thick there.

Londonderry Township.—This township has little of the Pittsburgh coal. The largest area is in the southeast corner in sections 4, 5, 10 and 11. In sections 13, 28, 29 and 35, small outliers are found, which are of little economic value even for local use. Through the southeast corner the coal usually has the sandstone roof, but in some places clay shale takes its place either partially or entirely. The coal averages about four feet thick with the two partings as found about Fairview. In the outliers in sections 28, 29 and 35, the coal is reported from three and one-half to four feet thick, with no roof coal. Many horsebacks and clay veins have been found where these outliers have been worked.

Richland and Wills Townships.—These townships have no important area of the Pittsburgh coal, only a few small outliers being found in them. In Richland township small areas are found in the high hills about the village of New Gottingen—two small areas of a few acres each to the west and southwest, and a small area in sections 12 and 13, to the southeast of the village. The thickness could not be learned.

The only area in Wills township is in section 20, possibly extending into section 19. The area is very small, and as no openings have been made, the thickness was not learned. Small outliers have been reported in section 17, of Madison township, and in sections 10 and 17, of Jefferson township, but the localities were not visited, as they are of no economic value.

Spencer Township.—The horizon of the Pittsburgh coal is found in this township, but the coal is of little value and cannot compete with the Meigs Creek, or Cumberland coal, found from 90 to 100 feet above it.

From southern Guernsey county to the southwest through Noble and Morgan counties, the Pittsburgh coal is of very little value. It becomes thin and very irregular, sometimes disappearing altogether. It regains its thickness and value in Athens and Meigs counties, where it is known as the Pomeroy coal.

The accompanying map shows the area underlaid by this noble vein of coal in Jefferson, Belmont and Guernsey counties, except Madison, Wills, Richland and Spencer townships of Guernsey county.

The western outcrop of the coal sweeps around through Harrison county, where there is much good coal in this seam, but there was not time to follow it through that county. Hence that field is left for a future report.

The composition of the Pittsburgh seam in two of the Cadiz mines is appended: (*Lord.*)

	1	2
Moisture	2.90	2.92
Volatile combustible matter	39.85	41.00
Fixed carbon	49.25	49.57
Ash	8.00	6.51
Sulphur	3.74	3.79

1. Cadiz Coal Company, Porter mine.
2. Cadiz Coal Company, Rutan mine.

To allow comparison with the best phases of the Pittsburgh seam, the following analyses of the coal from the several pools of the Youghiogheny field are appended. The coals were sampled from stock in the Cincinnati market, and were not therefore fresh. They were analyzed by the same method that has been employed in the examination of our own coals. The figures are as follows: (*Lord.*)

	1	2	3	4
Moisture	1.39	1.40	1.43	1.23
Volatile combustible matter	36.18	39.54	36.83	34.65
Fixed carbon	57.36	55 31	57.25	56.22
Ash	5.07	3.75	4.49	7.90
Sulphur	0.79	1.08	0.95	1.28

1. 1st Pool coal.
2. 2d Pool coal.
3. 3d Pool coal.
4. 4th Pool coal.

CHAPTER XI.

THE POMEROY AND FEDERAL CREEK COAL FIELD.

By Ellis Lovejoy, E. M.

Under the head of The Pomeroy and Federal Creek Coal Field will be considered that portion of the Pittsburgh coal in southwestern Morgan county, Athens county, Meigs county, and northeastern Gallia county, together with sections showing the geological range of the field.

I. GEOLOGICAL STRUCTURE.

The following generalized section shows the structure of the Upper Coal Measures and a small portion of the Upper Barren Measures in Meigs county:

No.		Feet.	Feet.
1	Coal blossom		380
2	Shales, red and yellow, sometimes sandy	40 to 80	
3	Sandstone, Waynesburg, base of the Upper Barren Measures	30 to 50	
4	Coal blossom, Waynesburg		270
5	Shales alternating with laminated sandstones	120 to 140	
6	Coal blossom, Meigs Creek		140
7	Shales, often sandy	65 to 85	
8	Impure white limestone	1 to 3	75
9	Sandstone, Pittsburgh	40 to 80	
10	Coal	1 to 2	20
11	Shales	12 to 25	
12	Coal, Pomeroy	1 to 8	

Limestone.

A thin impure white limestone, No. 8 of the above section, found in sections 30 and 33, and fractional section 12, Salisbury township, and

section 4, Rutland township, is the only representative of the numerous seams found in the Upper Coal Measures to the north.

GENERALIZED SECTION OF THE UPPER COAL MEASURES IN ATHENS AND MORGAN COUNTIES.

No.		Feet.	Feet.
1	Macksburg sandstone	60	.....
2	Coal blossom, Macksburg, place of	.....	190
3	Shales	10	.....
4	White limestone	0 to 3	180
5	Shales	35	.....
6	White limestone	0 to 10	145
7	Shales	15	.....
8	White limestone	0 to 7	130
9	Shales	25	.....
10	White limestone	0 to 12	105
11	Shales	10	.....
12	Coal blossom, Meigs Creek	.....	95
13	Shales and laminated sandstone	20	.....
14	White limestone	0 to 15	75
15	Sandy shales	30	.....
16	White limestone	0 to 4	45
17	Red clay } or sandstone.	0 to 25	.....
18	Sandstone	10 to 75	.....
19	Pomeroy coal, top of	.....	.....

COALS.

The mark of a coal, 100 to 110 feet above the Waynesburg coal, may be seen in fractional sections 2 and 6, Chester township and in section 8, Sutton township. It belongs to the Upper Barren Measures.

The mark of the Waynesburg coal is found under the heavy sandrock through southern Chester township, and central and eastern Sutton township. It is of no economic value in this field.

Faint traces of a coal are found, 120 feet to 140 feet above the Pomeroy coal, in sections 7 and 31, Bedford township, and in section 30, Salisbury township.

A thin seam of coal, twenty feet to twenty-five feet above the Pomeroy coal, is found in Bedford and Scipio townships and to the north in Athens county. It is wanting in Salisbury, Sutton and Rutland townships. We will describe it more fully in connection with the Pomeroy coal along Shade Creek.

Limestones.

No single section of the limestones of the Upper Coal Measures in this portion of the field can be taken as a type section.

Unlike the regular persistent marine limestones of the Lower Measures, these white limestones appear and disappear, thicken up and thin out with confusing abruptness.

No. 4 of the above section may be seen in N. W. section 19, Marion township, Morgan county, and in fractional section 4, Lodi township, and section 18, Rome township, Athens county. At the latter place the following section was measured:

No.		Feet.	Feet.
1	Interval to top of hill containing sandstone	65	.....
2	Coal (?) blossom, faint, place of Macksburg	.....	185
3	Interval	8	.....
4	Top of white limestone	.....	177
5	Interval	37	.....
6	Top of white limestone	.....	140
7	Shale, where exposed	31	.....
8	Coal blossom, Meigs Creek	.....	109
9	Shales	54	.....
10	Interval, not exposed	33	.....
11	Sandstone	22	.....
12	Top of Pomeroy coal	.....	0

The limestones, Nos. 6, 8 and 10 of the general section, must be considered collectively. They belong between the Meigs Creek and Macksburg coals. In section 14, Union township, Morgan county, is a single seam, 126 to 133 feet, inclusive, above the Pomeroy coal. In S. E. section 32, Marion township, are two beds at 99 and 142 feet, respectively, above the Pomeroy coal. In N. E. section 25, Marion township, we find two beds at 135 feet and at 141 to 153 feet. In S. E. section 30, Bern township, Athens county, two beds at 131 and 147 feet.

In fractional section 2, Ames township, but one of this series at 103 feet. Likewise at Evansville, in Lodi township, is there but one, at 107 feet.

In W. section 32, Canaan township, we find a single seam, at 106 feet. In section 21, Union township, we find a series of limestones and shales extending from 104 to 132 feet above the coal with no well marked interval of separation. The same is true in fractional section 31, Marion township, where the series extends from 99 to 126 feet above the coal.

The white limestone, No. 14 of the general section, seventy-five feet above the Pomeroy coal, is the most persistent. It alone, in Meigs county, finds a place in the general section.

The following section, measured on the Gifford farm, in section 30, Bern township, shows the position of the limestone:

No.		Feet.
1	White limestone	147
2	Buff limestone	131
3	White limestone	74
4	Pomeroy coal, top of	0

The intervals are omitted. The sandstone over the Pomeroy coal was seen thirty-nine feet thick.

In fractional section 2, Ames township, Athens county, the limestone, No. 14 of the general section, is seen fifteen feet thick; in N. E. section 7, Canaan township, eleven feet; in S. W. section 26, Rome township, thirteen feet. In the northern portion of the field, in section 4, Union township, Morgan county, the interval between the limestone and the Pomeroy coal was measured seventy-four feet. To the south, in N. E. section 33, Salisbury township, Meigs county, the interval was seventy-five feet. In the latter place the strata were exposed for 110 feet above the limestone with no sign of coal or limestone.

The limestone forty-five feet above the Pomeroy coal, is often wanting, the place being occupied by the Pomeroy sandstone. It was seen in N. W. section 8, and fractional section 32, Homer township, Morgan county, and in N. W. section 23, Ames township, Athens county.

Coals.

The coals above the Pomeroy coal are of little value. The coal blossom, 190 feet above the Pomeroy coal, is the equivalent of the Macksburg or "Sandstone Vein" of Washington county.

The marks of it were found in section 18, Rome township, and in fractional section 5, Bern township, Athens county. The overlying sandstone accompanied it in both instances.

The coal ninety-five feet above the Pomeroy coal, is the equivalent of the Meigs Creek coal, of eastern Morgan county, and of the "Limestone Vein," of Washington county. Blossoms of it were seen in sections 30, 24 and 23, Ames township, Athens county. It is found along Big Run, in Rome township, and along Marietta Run, in Bern township. At the mouth of the latter run the interval between this coal and the Pomeroy coal is increased to 117 feet. It is mined for local use along Coal Run, in S. E. Marion township, also in Windsor township, Morgan county.

Clay.

The upper portion of the Pomeroy sandstone is sometimes replaced by a bed of red clay.

It is well shown on the Mansfield Petroleum Company's land at Joy, and on Linscott Run, section 7, Homer township, Morgan county.

Generalized Section of the Lower Barren Measures.

No.		Feet.	Feet.
1	Pomeroy coal, base of U. C. Measures		360
2	Shales	2 to 20	
3	White limestone, Pittsburgh	0 to 3	
4	Shales	40 to 50	
5	Sandstone	30 to 50	
6	Black slate or slaty coal		300
7	White limestone	1 to 8	
8	Shales, often sandy	60 to 70	
9	Ames limestone	6 in. to 15	205
10	Shales	0 to 10	
11	Thin coal		195
12	Shales	20 to 30	
13	Coal	0 to 3	160
14	Shales or sandstone	2 to 10	
15	Ewing limestone	0 to 3	150
16	Shales, often sandy	15 to 30	
17	Patriot coal	0 to 2	135
18	Sandstone or shale	15 to 30	
19	Cambridge limestone or flint	1 to 5	105
20	Shales	0 to 20	
21	Coal		90
22	Shales	5 to 15	
23	Limestone or flint	0 to 6	80
24	Shale or sandstone	10 to 16	
25	Brush Creek coal		70
26	Shales	5 to 10	
27	Mahoning sandstone	55 to 70	
28	Upper Freeport coal, top of L. C. Measures		0

The lower Barren Measures are not, as the name would indicate, barren. We find in them six coals and six limestones.

Limestones.

The Pittsburgh limestone, a white, fresh water limestone, usually accompanies the Pomeroy coal.

Nos. 6 and 7 of the general section are local formations. Individual sections containing them will be given when we come to speak of the coal along Long Run.

Three thin local limestones or limestone ores, not shown in the general section, are found between the limestone marked seven in the section and the Ames limestone. One at sixty feet to sixty-five feet above the Ames; one at forty-five to fifty feet above the Ames; and the third, thirty feet above the Ames.

They may be seen in Athens and Alexander townships, Athens county.

The Ames limestone is the first marine limestone found in descending the scale.

A firm, highly fossiliferous rock, twelve inches to thirty-six inches thick, its western outcrop may be followed continuously from the north, through western Morgan county and across Athens county. In Morgan county, it is found from 100 feet to 120 feet above the Cambridge limestone, and from 145 feet to 170 feet below the Pomeroy coal. In Athens county, the interval between it and the Cambridge is decreased to from seventy feet to ninety feet.

In Scipio and Rutland townships, Meigs county, it becomes a bed of yellow fossiliferous shale, with more or less limestone interstratified, eight feet to fifteen feet thick. These beds of shale are well shown along Muddy Fork of Leading Creek in southwestern Scipio township, and along the west branch of Little Leading Creek from Harrisonville, Scipio township, to the northwest.

In Columbia and Salem townships, Meigs county, and in Morgan township, Gallia county, it is a thin impure limestone, yet still highly fossiliferous. It is found in this southern portion of the field from eighty feet to ninety feet above the Cambridge limestone.

The Ewing limestone is subject to many changes in character. In Malta and Bloom townships, Morgan county, it is a coarse conglomerate. In section 32, Deerfield township, it is a nodular blue carbonate containing 16.50 per cent. of iron. On Little Willow Creek, section 34, Canaan township, Athens county, it becomes an impure white limestone. In Lee township, it becomes again a conglomerate. In N. E. section 5, Salem township, Meigs county, we find a conglomerate. In section 30,

Addison township, Gallia county, an impure white limestone is found at this horizon. In N. E. Springfield township, the Ewing becomes a fine-grained conglomerate.

The Cambridge limestone or flint is found through the western portion of the field. In northern Morgan county, it is a flint rock from five to eight feet thick. In section 8, Union township, it comes to the surface, in the bed of the east branch of Sunday Creek, a limestone eighteen to twenty-four inches thick. It holds thus through eastern Trimble, Dover, and Athens townships, Athens county. It disappears in the bed of the Hocking River, in section 31, Canaan township. In Alexander township it becomes again a flinty limestone. Here also a second flint comes in five to ten feet below the Cambridge.

These twin seams hold through Lee township and Columbia township, Meigs county. In northern Columbia township, the lower seam becomes six feet thick and the upper one five feet, with an interval of twenty feet between them. In section 24, the upper seam is eight to fourteen inches thick, the lower one twenty inches, with an interval of twenty-five feet. A thin coal is found in the interval, fifteen feet from the lower limestone.

An excellent section was measured in section 16, Columbia township, which is herewith given in full:

1.	Fossiliferous limestone, Cambridge		12 inches.
2.	Interval not exposed	19 feet.	
3.	Coal blossom		
4.	Shale	8 "	
5.	Fossiliferous limestone		24 inches.
6.	Shale	16 "	
7.	Brush Creek Coal { Coal, 4 inches / Clay, 14 inches / Coal, 12 inches }		30 inches.
8.	Shale	9 "	
9.	Mahoning sandstone	56 "	
10.	Upper Freeport Coal in bed of run	...	...

The Upper Freeport coal of this section has been mined for local use. The limestones are quite sandy, but have lost their flinty character.

We lose the lower limestone in Salem township. The upper seam ranges from twelve to thirty inches thick and is sufficiently pure for the manufacture of lime. It holds this through Morgan and Springfield townships, Gallia county.

Coals.

A thin coal of no economic importance often accompanies the Ames limestone.

From twenty-five to forty feet below the Ames limestone is found a quite persistent seam of coal, which is occasionally mined for local use.

The following section, which shows the place of these coals, was measured in section 27, York township, Morgan county. The intervals were not exposed and are omitted:

1. Coal blossom, No. 11, of general section ..... 99 feet.
2. Coal, 6 inches, sandstone roof, No. 13, general section ..... 81 "
3. Patriot coal, fossil shale roof, 18 to 22 inches thick..... 42 "
4. Cambridge flint in bed of run..... 0 "

The Ames limestone was found above the upper coal. Similar sections were found in sections 3 and 11, Deerfield township. In the latter section, on Oil Spring Run, the two lower coals have been worked by stripping. An interesting section, which shows the position of the coals with reference to the Ewing as well as the Ames limestone, was measured in section 32, Deerfield township.

It is as follows:

1. Ames limestone, 21 inches ..... 77 feet.
2. Coal blossom, (No. 13, of general section) ..... 45 "
3. Limestone ore, Ewing limestone ..... 29 "
4. Patriot coal, fossil ferous shale roof, 22 inches ..... 0 "

The coal, No 13 of the general section, is mined in section 6, Salem township, Meigs county, where it has the following structure:

1. Coal ..... 14 inches.
2. Slate ..... 3 "
3. Coal ..... 23 "

The Patriot coal gets its name from Patriot, Gallia county. It lies from eighteen to forty-five feet above the Cambridge limestone. A highly fossiliferous shale roof which this coal carries serves to distinguish it from other coals of the Lower Barren Measures. It is a quite persistent seam. We find it through Bloom, Deerfield and Malta townships, Morgan county, where it is variously reported from eighteen to thirty six inches thick. It has been mined for local use by stripping, and is reported an excellent grate coal. In Athens county it is found in section 1, Trimble town ship; in lot 91, section 20, Athens township; in lot 4, section 23, Alexander township; and in section 23, Lee township.

In Meigs county we find it in eastern Columbia township and western Scipio township. Also at Langsville, Rutland township.

In N. E. section 5, Salem township, it becomes an impure cannel coal ten inches to fourteen inches thick. It here carries a heavy sandstone roof. The thin coal which accompanies the Cambridge limestone is of no economic value.

Traces of the Brush Creek coal are found in York township, Morgan county. In section 16, Lee township, Athens county, it has been mined for local use. In section 16, Columbia township, Meigs county, it has, on the outcrop, the following:

Coal	4 inches.
Clay	14 "
Coal	12 "

On Buzzard's Run, section 24, Columbia township, we find it from six to twenty-two inches thick. The Cambridge limestone and its companion seam, with the thin coal between them, are also found here. Blossoms of the Brush Creek coal were seen in section 35 and fractional section 17, Columbia township.

The Upper Freeport coal belongs to the Lower Coal Measures. For a description of it, see Geology of Ohio, Vols. III and V. In Meigs county it is mined for local use in fractional section 17, Columbia township, where it has the following structure:

Coal	10–20 inches.
Slate	2–5 "
Coal	13–18 "

It is also mined in section 36, Salem township, where it was seen forty inches thick without the slate parting.

Sandstone.

We have spoken of the Waynesburg sandstone of the Upper Barren Measures and of the Macksburg and Pomeroy sandstone of the Upper Coal Measures. In the Lower Barren Measures are two which play an important part in the topography of this field. In Lodi and Canaan townships, Athens county, between the Ames limestone and Pomeroy coal, is a sandstone from thirty to ninety feet thick. North of the Hocking River in Canaan township, it reaches quite up to the place of the Pomeroy coal, while south of the river it is separated from the coal by twenty to thirty feet of slate.

We find a similar sandstone at the same horizon, near Langsville, Rutland township, Meigs county. A thin persistent sandstone is found overlying the Cambridge limestone.

Under cover it becomes the "oil rock" of Federal Creek, Homer township, and of Buck Run, Union township, Morgan county.

It is also the "first oil sand" of Macksburg, and of Cow Run, Washington county.

The Mahoning sandstone, overlying the Upper Freeport coal, is the

remaining heavy sandstone of the Lower Barren Measures. It may be seen in Columbia township, Meigs county, from fifty to sixty feet thick.

II. THE POMEROY AND FEDERAL CREEK COAL FIELD.

The map accompanying this report shows the western outcrop and developed area of the Pomeroy and Federal Creek coal.

For convenience in describing the coal, the field will be considered under four heads, as follows:

1. The Pomeroy field.
2. The Shade Creek field.
3. The Long Run field.
4. The Federal Creek field.

1. The Pomeroy field is by far the most important one. Above drainage we find it in four townships, viz., Cheshire, Gallia county, Sutton, Salisbury and Rutland, Meigs county.

Along the Ohio River, in the first three townships named, it is mined in the large way, at Antiquity, Syracuse, Minersville, Pomeroy, and in Watt's mine, and Karr's mine near Cheshire.

The country banks are quite numerous. Throughout the body of the field the coal is very regular; a single section becomes a type section for a considerable portion of the field.

Section of the coal in the Peacock mine at Pomeroy:

Coal	8 to 14	inches.
Horn coal	3	"
Coal	42 to 47	"
Clay	4	"
Coal	7	"

Sometimes a thin streak of slate is found in the main bench, fifteen to seventeen inches from the bottom. The roof coal and horn coal are used in the salt-works. The thin under coal is not mined. With the exception of the under clay and coal, which could not be seen, the structure of the coal at Syracuse, Minersville, and along Karr's Run, is the same as that given above.

Section of the coal from N. W. section 26, Salisbury township:

Roof coal	12	inches.
Horn coal	1½	"
Coal	4½	"
Clay	7 to 11	"
Coal	4	"

Excepting, as before, the under clay and coal, the above section is practically the same as that at Middleport and in fractional section 36, Salisbury township, where sections were measured.

The comparison of this section with that of the Peacock mine shows but little variation in the structure of the seam. In T. H. King's mine, lot 315, Salisbury township, the main bench thickens to forty-eight inches, the roof coal and horn coal being the same as in the preceding section.

In Gardner's bank, N. E. section 1, Rutland township, the coal has the following structure:

Roof coal	8 to 12 inches.
Horn "	3 "
Coal	36½ "

The following analyses show the character of the coal:

	1	2	3	4	5	6	7	8	9	10
Moisture	4.75	4.72	3.59	5 04	6.03	3.97	4.58	4.70	5.20	5.62
Vol. comb. matter	39.15	38 95	40 17	37.58	34 61	40.51	39.90	38 79	33 94	37.42
Fixed carbon	50.35	46.21	47 89	51.82	54.09	48.53	50.40	50 19	50 14	50.88
Ash	5.75	10.12	8.14	5 56	5.27	6.99	5.12	6 32	5.72	6.08
Sulphur	0.77	2.03	1.96	1.49	0.71	2.13	1 33	1.46	1.43	0 86

1. Peacock mine, Pomeroy.
2. Middleport.
3. Minersville.
4. Syracuse.
5. T. H. King, lot 315, Salisbury.
6. J. Thomas, N. W. section 26, Salisbury.
7. Fractional section 36, Salisbury.
8. Eversbach's mine, Pomeroy.
9. Karr's Run, N. W. section 2, Sutton.
10. Gardiner's mine, N.E. section 1, Rutland.

These analyses show that the body of the Pomeroy field contains a coal of considerable excellence.

It is fairly low in ash, moisture and sulphur. In fixed carbon it ranks between the Middle Kittanning and Upper Freeport coals.

In Watt's mine, two miles below Middleport, the coal has the following structure:

Roof coal	24 inches.
Slate parting	...
Coal	6½ "
Slate parting	...
Coal	37 "

The lower slate parting is called "the band." The upper one is quite thin, but it marks the boundary of the roof coal, which is not mined.

The analysis of the coal is as follows: (*Lord.*)

	(1.)	(2.)
Moisture	3.96	4.81
Volatile and combustible matter	39.78	38.60
Fixed carbon	45.85	50 05
Ash	10.41	6.51
Sulphur	4 34	1.42

1. Watt's mine.

2. Average of the ten analyses on preceding page. A considerable change, not only in the structure of the seam, but in the character as well, appears in Watt's coal.

The structure of the coal in Harper's bank, N. W. section 25, Salisbury township, is shown in the following section.

Roof coal	11 inches.
Slate parting	...
Horn coal	3 "
Hard coal	9 "
Coal	42 "
Clay not mined	4½ "
Coal "	5 "

In the Big Kyger Coal Works, J. Blackburn & Son, lot 396, S. E. section 9, Cheshire township, Gallia county, the coal has the following structure:

Coal	9 inches.
Slate	½ to 2 inches.
Coal	39 inches.

The horn coal of the Pomeroy section is not recognized. In Hysell's bank, lot 382, N. W. section 15, Cheshire township, the structure of the coal is as follows:

Coal	12 inches.
Slate parting	...
Coal	13 "
Slate parting	...
Coal	30 "

This triple structure of the seam is often recognized in the Shade Creek coal and in the lower bench of the Federal Creek coal, but cannot be traced through the body of the Pomeroy field.

The coal in H. B. Smith's bank, lot 6, Cheshire township, also shows a triple structure.

Coal	12 inches.
Slate	½ to 1½ inches.
Coal	9 inches.
Slate parting	...
Coal	28 "

The analyses of these coals are herewith given: (*Lord.*)

	1.	2.	3.
Moisture	5.24	5.01	4.83
Volatile and combustible matter	38.82	40 74	40.41
Fixed carbon	48 42	48.12	46 88
Ash	7.52	6.13	7.88
Sulphur	1.69	2.48	2.52

No. 1. Big Kyger Coal Works.
No. 2. Hysell's coal.
No. 3. H. B. Smith's coal.

A comparison with the first ten analyses given shows a slight decrease in the fixed carbon, and an increase in the ash and sulphur.

We now come to speak of the boundary of the area of minable coal in the Pomeroy field, together with the adjacent area of thin coal.

At the boundary, in many places, the coal shows a marked thickening, and with this thickening comes a number of slate partings unknown in the center of the field.

Beyond the boundary the coal suddenly drops to thirty inches or less, with two, or more often, but one slate parting.

A few sections will be given to show the structure of the coal at and beyond the boundary.

The following section of the coal was measured in J. Martin's bank, N. W. section 16, Salisbury township:

Coal	2 inches.
Slate	1½ "
Horn coal	2 "
Hard coal	16 "
Coal	27 "
Slate	7 "
Coal (not mined)	4 "

With the exception of the slate parting near the top, the structure of this coal varies but little from that of the normal seam.

In the adjoining quarter section to the north, S. E. section 23, Salisbury township, on A. Houck's land, the structure is as follows:

Coal	5 inches.
Slate parting	...
Coal	19 inches.
Slate	9 "
Coal	3 "

A little further to the north, in the same quarter with the last section, the seam becomes as follows:

Coal	17 inches.
Slate	8 "
Coal	2 "

To the north, the coal holds thin till it runs under in section 24, Salisbury township.

From the mouth of Ball's Run, fractional section 3, Salisbury township, to its head where the coal runs under in section 30, the seam is thin, variously reported from 12 inches to 34 inches, with a single slate seam.

On E. Deihl's land, S. W. section 34, Salisbury township, the structure of the coal is as follows:

Slaty roof coal	21 inches.
Sandstone	3 "
Coal	$2\frac{1}{2}$ "
Slate parting	...
Coal	3 "
Slate	1 "
Coal	25 "
Slate	5 "
Coal, not mined	4 "

Here we have a total of seven feet and two and one-half inches, but with it comes four slate partings and a thin parting of sandstone,

In N. W. section 34, Salisbury township, on R. Chase's land, we see the thin coal.

Coal	23 inches.
Slate	$2\frac{1}{2}$ "
Coal	5 "

The coal in S. S. Smith's bank, S. W. section 4, Rutland township, has a total thickness of sixty-eight inches, with nine inches of slate, distributed as follows: One inch, sixteen inches from the bottom; three-fourths inch, twenty three inches from the bottom, and seven inches, twenty-four inches from the top. In the adjoining hills to the north the coal is reported eighteen inches thick.

In W. section 3, Rutland township, in J. E. Stansbury's bank, the coal is reported nine feet nine inches, including twenty one inches of slate.

A section of the coal in section 3, Rutland township, given in Vol. I, Ohio Geological Survey, page 250, shows a total thickness of ten feet, including twenty-eight inches of slate and shale.

In fractional section six, Rutland township, the following section was measured:

Slaty roof coal	34 inches.
Slate parting	...
Coal	12 "
Slate	7 "
Coal	3 "
Slate	2 "
Coal	8 "
Slate	3 "
Coal	17 "
Slate parting	...
Coal	5 "

In the same hill with the coal of the last section, on J. Black's land, fractional section 6, Rutland township, we find the coal as follows:

Coal	14 inches.
Slate parting	...
Coal	9 "
Slate	1 inch.
Coal	6 inches.

Here, again, we have the triple structure, that is shown in the coal in Cheshire township, Gallia county.

The slate partings in the thick coal rapidly disappear to the south and southeast, toward the center of the Pomeroy field.

In Stevens's bank, fractional section 6, Rutland township, in the same hill with the coal of the preceding sections, the 3-inch slate band, twenty-two inches from the bottom, has disappeared.

In S. Paine's bank, section 8, Rutland township, the coal has a total thickness of seven feet, with but two thin bands of slate, one six inches from the bottom and the other under the roof coal thirty-one inches from the top.

In L. M. Higley's bank, section 7, Rutland township, we find two slate bands; a 5-inch band, four inches from the bottom, and an inch band, twenty-four inches from the top.

In Hooper's bank, fractional section 7, Rutland township, the coal measures five feet six inches, four feet of which is mined.

Samples from Higley's and Hooper's banks show the following composition:

	(1)	(2)
Moisture	3.94	5.34
Volatile combustible matter	44.54	39.04
Fixed carbon	43.80	48 88
Ash	7.72	6.74
Sulphur	3.78	1.99

No. 1. Hooper's coal.
No. 2. L. M. Higley's coal.

No analyses of the coal along the boundary have been made. Mr. Hooper's coal lies near the western boundary, yet it has not the thickness and does not contain the numerous slate bands of the coal on Eiselstein's and Hugg's lands, a mile to the west. In the latter place, fractional section 1, Rutland, the coal has a total thickness of seven feet four inches, including five slate bands.

None of the slate bands exceed two inches in thickness, but they are so distributed that, excepting thirty-six inches of slate roof coal, the thickest bench of solid coal is sixteen inches. In northwest section 25, Rutland township, the coal was measured twenty-seven inches and thirty-one inches, with no slate partings.

In Gallia county the coal does not show the thickness seen in Meigs county. The structure of the coal on H. B. Smith's land, northwest of Kygersville, Cheshire township, has already been given.

In northeast section 26, Cheshire township, the coal is four feet thick, with three thin streaks of slate, one twenty-six inches from the bottom, a second, thirty inches from the bottom, and the third, six inches from the top.

In northeast section 6, Springfield township, the coal measured twenty-eight inches, with no partings.

In northwest section 29, Addison township, thirty inches; in northwest section 24, Addison township, thirty-five inches, with a slate streak nine inches from the top. This completes the circuit.

South of Campaign Creek, in Addison and Gallipolis townships, the coal is very thin, oftentimes wanting.

The Shade Creek Field.

The Shade Creek Field includes portions of Bedford and Scipio townships, Meigs county, and of Lodi and Alexander townships, Athens county.

With the exception of the western outcrop, the field is drained by Shade creek and its branches.

Where the coal becomes of minable thickness on Kingsbury Run, Bedford township, north of the interval of thin coal indicated on the map, the structure of the Pomeroy coal is no longer recognized. The thin under coal is gone; the inferior roof coal cannot be distinguished; the horn coal is unknown. The sandrock which comes down on the coal in the south is now separated from the coal by fifteen to twenty feet of shale capped by a thin coal.

In a few places a white limestone is found between the two coals. The Pittsburgh limestone, under the Pomeroy coal, holds quite steady throughout this field. Both coals are mined for local use. The following sections show the structure of the upper or rider seam.

	(1)	(2)	(3)	(4)
Coal	4	6	12	17
Slate	½	4	2	6
Coal	25	22	8	5

1. N. W. section 11, Scipio township, Meigs county.
2. Fractional section 2, Scipio township, Meigs county.
3. S. E. section 29, Bedford township, Meigs county.
4. S. W. section 26, Bedford township, Meigs county.

In Athens county the upper seam is thin and seldom mined. We find it at Hamilton's Mills, eighteen feet above the Pomeroy coal. It is reported eighteen inches thick. Along Pratt's fork in Lodi township it is variously reported twelve to thirty-six inches thick. At Evansville, section 16, Lodi township, it is found twelve feet above the Pomeroy coal. It is here twelve inches thick.

The lower or Pomeroy coal proper is by far the most important. It is mined to supply the local trade in the following banks:

Alkire's and Davis' banks, section 2, Scipio.
Mill bank at Bungtown, Bedford.
J. E. Swacy, S. E. section 29, Bedford.
Hart's, fractional section 4, Scipio.
Hamilton's Mill, S. E. Alexander.
Pleasanton, Alexander.
Williams' bank, N. W., section 19, Lodi.
Evansville, section 16, Lodi.

The normal structure of the coal is indicated by the following section measured at Hamilton's mill in S. E. Alexander township.

Coal	9 inches.
Slate streak	...
Coal	30 "
Slate streak	...
Coal	12 "

The slate streaks are very thin, but are wonderfully steady throughout the field.

The only place where both of them were not found was at Evansville, where the coal was measured forty-five inches with a single slate streak seventeen inches from the top. The greatest variation is in the upper bench. The middle bench ranges between seventeen and twenty-one inches. The lower bench from nine to twelve inches, usually the latter. Samples of the coal from Sevacy's and Hart's bank show the following composition.

	(1)	(2)
Moisture	4.17	5.41
Volatile combustible matter	41.33	40.16
Fixed carbon	47.04	46.31
Ash	7.46	8.12
Sulphur	5.83	5.08

No. 1. Jas. E. Levacy's bank.
No. 2. Hart's bank.

These analyses show a decided falling off in fixed carbon from the coal of the body of the Pomeroy field. The high percentage of sulphur is decidedly against the coal.

The whole seam is mined. The maximum thickness was seen in Williams' bank, N. W. section 19, Lodi township, Athens county. The section of the coal is herewith given.

Coal	7 inches.
Slate streak	...
Coal	$8\frac{1}{2}$ "
Slate streak	...
Coal	6 "
Slate streak	...
Coal	15 "
Slate streak	...
Coal	17 "

In this section, in addition to the two slate partings which hold throughout the field, we find two other partings which split the upper

and middle benches. These two partings are by no means local. We find the upper one in the coal at Pleasanton, Alexander township. We also find it in the Federal Creek coal.

On Mr. Williams' place the Pittsburgh lime was seen, thirty inches thick, from two to four feet below the coal. The upper or rider-coal is reported here thirty-six inches thick. A thin nodular limestone is found between the two coals.

The Long Run Field.

The Long Run field is a comparatively narrow spur from the Shade Creek coal. It extends from the mouth of Long Run in section 23, Lodi township to the northern part of section 34, Canaan township. In width, its extent is quite limited. On Douglas branch of Shade, a little more than a mile to the west, there is no coal of mineable thickness. A mile to the east brings us into the branches of Willow Creek where, except a small area on the Middle branch in section 19, Canaan and section 18, Lodi, no coal mined or reported of mineable thickness.

The following sections were measured to determine the place of the Long Run coal:

Section in lot 40, section 8, Athens township:

1.	Coal blossom, Pomeroy	...
2.	Top of white limestone, thickness not seen	...
3.	Interval	57 feet.
4.	Coal blossom	...
5.	Top of white limestone, thickness not seen	...
6.	Interval	114 feet.
7.	Ames limestone	1 foot.
8.	Interval	80 feet.
9.	Cambridge limestone	1 foot.

The coal or slate underlaid by a white limestone, 114 feet above the Ames limestone, is an unusual element in the scale, and a puzzling one in the absence of well-marked guides.

In section 1, Athens township, the following was seen:

1.	Coal blossom	...
2.	Interval	11 feet.
3	Coal blossom, Pomeroy coal	...
4.	Interval	5 "
5.	Top of white limestone, thickness not seen	...
6.	Interval	54 "
7.	Slaty coal, false bedded, under a heavy sand-rock	...
8.	Interval	5 "
9.	Top of white limestone in bed of Douglas run	...

In this section we find the coal and limestone, which in the last section lies 114 feet above the Ames. We have also the Pittsburgh limestone and the Pomeroy coal of the last section.

Besides these we have a mark of the rider coal so steady in the Shade Creek field. The heavy sand-rock over the slaty coal may be followed continuously down Douglas branch and up Long Run. On Long Run, in section 30, Lodi township, a coal was reported in the bed of the run. The Pomeroy coal here lies sixty feet above the bed of the run, the interval being occupied by the heavy sand-rock. The structure of the Pomeroy coal at this place is as follows:

Coal	24 inches.
Slate	12 "
Coal	4 "
Clay	12 "
Coal	36 "

At the head of Long Run, in section 32, Canaan township, a section was measured which is here given in full:

1.	White limestone	1 foot.
2.	Sandy shale and laminated sandstone	47 feet.
3.	Coal (?) blossom, faint	...
4.	Shales, often sandy	37 "
5.	White limestone	1 foot.
6.	Red shales	14 feet.
7.	Coal blossom, rider seam	...
8.	Shales	15 "
9.	Coal, Pomeroy, mined	4 "
10.	Red shales	28 "
11.	Not seen	16 "
12.	Sandstone to bed of Long Run	30 "

Passing now to Little Willow Creek, in section 33, Canaan township, we find the following:

1.	Coal, Pomeroy, mined	4 feet to 8 feet.
2.	Interval containing heavy sand-rock	170 "
3.	Ames limestone	1 foot.

The Ewing limestone is found here in the bed of Little Willow Creek, and the Cambridge limestone in the bed of the Hocking River.

In Jesse Fisterwald's mine, section 33, Canaan township, the Pomeroy coal has the following structure:

Coal	4 to 7 inches.
Slate streak	...
Coal	25 inches.
Slate	7 "

Coal	5 inches.
Clay	10 "
Coal	6 "
Slate streak	...
Coal	30 "

A comparison of this section, with the sections of the Federal Creek coal, can leave little doubt in regard to identity.

The analyses of Fisterwald's coal is herewith given:

	1.	2.
Moisture	5.44	5.09
Volatile combustible matter	40.13	37.85
Fixed carbon	48.04	50.58
Ash	6.39	6.48
Sulphur	2.76	3.15

No. 1. Upper bench.
No. 2. Lower bench.

With the exception of sulphur, the composition of the lower bench differs but little from the composition of the coal in the Pomeroy field.

The upper bench, which is considered the better coal, shows a slight improvement in the sulphur, but a marked falling off in fixed carbon.

As previously stated, the coal is found throughout the length of Long Run, and with one exception already noted, it is thin or wanting on the runs to the east and to the west.

On the east side of Long Run the coal is found in good force, and is mined or stripped on nearly every farm. The lower bench ranges from thirty-six inches to forty-two inches; the upper bench from a few inches to the thickness already given in the preceding sections. On the west side of the run, however, but one or two attempts have ever been made to mine the coal. The upper bench is reported absent, and the lower bench less than thirty six inches thick. With these reports before us we cannot hope for any considerable area of mineable coal west of Long Run. To the east, on Willow creek, in section 19, Canaan township, the upper bench is represented by twelve inches of slaty coal. The lower bench is from thirty inches to thirty-six inches thick. Through eastern Athens township, northern and eastern Canaan township, and southern and central Ames township, the Pomeroy coal is wanting.

The Federal Creek Field.

The Federal Creek field is second in importance. It includes parts of Rome, Bern and Ames townships, Athens county, Homer and Marion townships, Morgan county.

The coal is mined throughout the field for local use. With the advent of the Marietta Mineral Railway in 1885, three mines were opened in the southeastern part of the field, with facilities for shipping coal. They are as follows:

1. Coulter & Butts, N. W. section 18, Rome township.
2. Heyburn Bros. & Co., S. W. section 13, Bern township.
3. Wickham, Haines and Schuler, N. E. section 19, Bern township.

In Heyburn Bros. & Co.'s mine the coal reaches its maximum thickness as follows:

Coal	22 inches.
Slate streak	...
Coal	28 "
Slate	7 "
Coal	3 "
Clay	12 "
Coal	12 "
Slate streak	...
Coal	36 "

Both benches are mined for the general market.

A sample of the coal from this mine shows the following composition:

Moisture	4.18
Volatile combustible matter	40.22
Fixed carbon	50.15
Ash	5.45
Sulphur	2.96

With the exception of the sulphur, the analysis of this coal compares very favorably with the average of the Pomeroy field.

In Coulter and Butt's mine the coal is not so thick. A section of it was measured as follows:

Coal	25 inches.
Slate	8 "
Coal	4 "
Clay	12 "
Coal	8 "
Slate streak	...
Coal	22 "
Slate streak	...
Coal	6 "

The coal tapped by these two mines is continuous. On the opposite side of Federal Creek, a little northwest of Heyburn Bros & Co.'s mine, in Wickham, Haines and Schuler's mine, the upper bench is thirty-seven inches with a slate streak eight inches from the top, and the lower bench is thirty-eight inches thick with a slate streak thirty inches from the bottom. In fractional section 25, Bern township, the upper bench is forty-five inches, and the lower bench forty-eight inches with two slate streaks, one fourteen inches from the top, and the other five inches from the bottom.

A comparison of the above sections with those of the Long Run coal, shows, that, though separated by a considerable area of barren territory, the conditions under which these coals were formed were identical. In the lower bench in Coulter and Butt's mine, and in Wilson's mine, fractional section 25, Bern township, we have duplicates of the triple structure so characteristic in the Shade Creek field. Additional sections will be given to show that this triple structure is not confined to these two mines in the Federal Creek field.

The thin rider coal, so persistent in the Shade Creek and Long Run fields, is not known north of the Hocking River. In the Federal Creek field, as in the Pomeroy field, its place is occupied by the Pomeroy sandstone. The Federal Creek coal comes above the bed of Federal Creek near the mouth of Big Run in section 18, Rome township. We find it along Federal Creek to section 26, Bern township, where it becomes thin, and along Marietta Run to where it goes under in fractional section 1, Bern township. From section 26, Bern township, to the west along Federal Creek and its southern branches, the coal is not found. In Bern township it comes in again on Sharp's Fork of Federal Creek, near the mouth, and it may be followed to the north.

Section of the coal in Wells's bank, fractional section 34, Bern township:

Roof coal, not mined, reported	36 inches.
Clay	12 "
Coal	12 "
Slate streak	...
Coal	32 "

In N. E. section 29, Bern township, in Gilchrist's bank, the coal has the following structure:

Coal	36 inches.
Slate	16 "
Clay	12 "
Coal	18 "
Slate streak	...
Coal	19 "
Slate streak	...
Coal	11 "

Here we have, again, the triple structure in the lower bench. To the north along Opossum Run, the upper bench becomes thin and unsteady.

The lower bench is mined in Caris and Edgerton's banks in section 19, Marion township, Morgan county. In Woodyard's bank, N. E. section 25, Marion township, the upper bench is eight inches and the lower bench forty inches.

The coal runs under in fractional section 32, Marion township, but becomes thin before reaching that place. Up Sharp's Fork, from the mouth of Opossum Run, section 29, Bern township, the coal is mined for local use.

The upper bench is quite unsteady. The Ames limestone comes above drainage in section 31, Marion township, and may be followed continuously to the northwest. Near Joy, in S. W. section 32, Marion township, the upper bench of the coal is sixteen inches, the lower bench is thirty six inches.

In N. W. section 2, Homer township, on the Mansfield Petroleum Company's land, the upper bench is thin, and the lower bench ranges from forty to forty-six inches. A sample from the Mansfield Petroleum Company's bank shows the following composition:

Moisture	4.55
Volatile combustible matter	39.99
Fixed carbon	45.46
Ash	10.00
Sulphur	4.89

It runs unusually high in ash and sulphur, and low in fixed carbon. To the north, the coal thins out in section 3, Homer township.

In fractional sections 1, 2 and 6, Homer township, both benches are found in full force.

The following section of the coal was measured in Berry's bank, fractional section 2, Homer township:

Coal	11 inches.
Slate streak	
Coal	
Clay	41 "
Coal	12 "
Slate streak	4½ "
Coal	
Slate streak	7½ "
Coal	
Slate streak	22 "
Coal	
	9½ "

A comparison of the sections in the Federal Creek and Long Run

fields show the persistency of the thin slate streak near the top of the upper bench.

The heavy slate band found in the coal on Federal Creek and Long Run is wanting in Homer township. A sample from the lower bench in Hogshead's bank, fractional section 6, Homer township, shows the following composition:

Moisture	5.30
Volatile combustible matter	40.18
Fixed carbon	48.50
Ash	6.02
Sulphur	2.87

The northern boundary of mineable coal in this part of the field is reached in section 16 and fractional section 4, Homer township. Only the lower bench is found at this limit. To the north, the coal drops to eighteen inches and less.

We have already spoken of the gap in the coal near the mouth of Sharp's Ford, Bern township, and of its extension to the west and south through Ames and Canaan townships.

To the northwest the coal comes in again in sections 11, 12 and 18, where it has been worked for many years to supply Amesville and vicinity.

In Rice's bank, section 11, Ames township, it has the following structure:

Coal, not mined	5 inches.
Clay	12 "
Coal	8 "
Slate streak	...
Coal	24 inches.
Slate streak	...
Coal	8 inches.

Through sections 3, 4 and 5, Ames township, the coal is reported thin or wanting. In the northern part of section 6, on Linscott Run, it is mined. From there we may follow it to the north into Morgan county. In section 7, Homer township, near where it runs under, it is thirty-three inches thick, with a slate streak eight inches from the bottom. In sections 30 and 36, Ames township, is a small area of the coal surrounded by comparatively barren territory.

In Bodeman & Wolf's bank the upper bench is represented by nineteen inches of slaty coal, while the lower bench is forty-eight inches thick. In Sears's bank, the upper coal is reported from twelve to eighteen inches thick, the lower bench from forty-eight to sixty inches. In Mason's bank the lower bench is reported forty-two inches.

In southwestern Homer township, Morgan county, the coal is thin or wanting.

From fractional section 31, through fractional sections 36, 18, 17 and 23, and into section 23, Homer township, the coal is mined for local use.

Similarly from fractional section 32, through fractional sections 24, 34 and 35, and section 29, one, and often both benches are found in good force.

In J. Steffy's bank, section 29, the structure of the coal is as follows:

Coal	20 inches.
Slate parting	...
Coal	24 inches.
Clay	12 "
Coal	4 "
Slate parting	...
Coal	12 inches.
Slate parting	...
Coal	23 inches.
Slate parting	...
Coal	8 inches.

In Howard's bank, section 29, the structure of the coal is the same as that given above.

On J. Shaner's place, fractional section 35, the upper bench is wanting. The lower bench is reported four feet thick. East of Bishopville is a small outlier of the coal mined for local use.

A sample of the coal from Steffy's bank has the following composition:

Moisture	5.39
Volatile combustible matter	41.18
Fixed carbon	46 32
Ash	7.11
Sulphur	4,16

The coal thins out in the northern part of Homer township, and holds thin to the north, through Union township.

CHAPTER XII.

THE MANUFACTURE OF SALT AND BROMINE.

By W. J. Root, E. M.

Geography.

Ohio is now the third state in the Union in the production of common salt. From the report of the Saginaw Board of Trade, containing therein statistics compiled by the Michigan Salt Association, we secure the following statistics on the production of salt in the United States for 1885.

Michigan	3,300,000	barrels.
New York	1,749,000	"
Ohio	530,000	"
Louisiana	330,000	"
West Virginia	200,000	"
California	176,000	"
Pennsylvania	170,000	"
Utah	96,000	"
Virginia	85,000	"
Illinois	50,000	"
Kentucky	16,000	"
Massachusetts	1,900	"
Total	6,703,900	barrels.

There was imported from foreign countries, 3,100,000 barrels, making a total consumption in the United States for 1885 of 9,803,900 barrels, equivalent to 2,745,092,000 pounds, or about 50 pounds of salt per capita. Of this vast amount, the Michigan Salt Association alone handled nearly three million barrels, which is nearly one half the total product of the United States and one-third of the total amount of salt consumed.

It is estimated that the product in Ohio the present season will exceed 515,000 barrels, being distributed as follows:

Meigs county	400,000 barrels.
Tuscarawas county	65,000 "
Morgan county	25,000 "
Columbiana county	20,000 "
Guernsey county	5,000 "
Total	515,000 barrels.

There are sixteen furnaces in Ohio at present, being distributed as follows:

Meigs county,	7	furnaces, average daily capacity	200	barrels each.
Tuscarawas county	3	" " " "	65	" "
Morgan "	4	" " " "	20	" "
Columbiana "	1	" " " "	65	" "
Guernsey "	1	" " " "	15	" "
	16			

Columbiana County.

But one furnace is now active in this county. It is located on the New Lisbon branch of the N. Y., P. & O R. R., a short distance from New Lisbon, and is owned by the New Lisbon Salt Company. The furnace was built in 1868. It has a daily capacity of sixty five barrels. Two wells furnish the necessary brine. They are drilled to a depth of 630 and 687 feet. The brine has a strength of 10° Beaume, as it comes from the wells. (For explanation of Beaume's hydrometer, see Process of Manufacturing.) The brines are quite impure, requiring a large settling capacity and yielding a high percentage of bitterns. The bitter water has no commercial value except as a fertilizer. Bromine is not present in sufficient quantity to pay for manufacturing. The steam and pan process combined is used in concentrating and graining. The furnace is located on the horizon of the Freeport coals, which are mined on the spot and brought directly to the furnace. About 350 bushels of coal is consumed daily. The works being isolated and some distance from any other salt producing centre, the product finds a ready market at a fair price among the small towns within easy reach by railroad transportation. The salt bears a good reputation in the markets where it is handled for table, dairy and general use. Considerable coarse salt is manufactured, which finds a ready sale as material for glazing in pottery and sewer pipe manufacture, in the immediate vicinity. Any impure salt, not otherwise marketable, is sold to the farmers of the vicinity, and used by them as a fertilizer.

Guernsey County.

But one furnace remains to represent the salt industry in this county. This furnace is located near Miller's Station, on the Cleveland

and Marietta R. R., about eight miles north of Cambridge. It is operated by Mr. Ad. Alexander, was built in 1859, and has been in continuous operation ever since. One well furnishes the brine. It is drilled to a depth of 430 feet. The brine is weak, but tolerably pure, standing at 5° B. as it comes from the well. No bromine is present and the bitterns are worthless. The furnace is small, having a daily capacity of less than ten barrels. The kettle and pan process combined is used in concentrating. Six kettles of about 100 gallons each, and one pan twenty-four by four and one-half feet do the work. The Middle Kittanning coal is mined on the spot and furnishes fuel for the furnace. From four to five tons are consumed daily. The salt is of fair quality and supplies a small local trade.

Morgan County.

The salt industry in Morgan county is centered along the Muskingum River, in the vicinity of Eagleport, about ten miles above McConnellsville. There is one furnace active below McConnellsville. The valley of the Muskingum River is the pioneer territory in Ohio in the production of salt.

Thirty-seven (37) furnaces once flourished along the river. Of this number but four remain. The most of these furnaces were built to burn the wood from the native forests, and they remain as they were built, the industry in later years not warranting further investment. They are kettle furnaces throughout, and of small capacity, the four furnaces representing a total daily capacity of eighty or ninety barrels only. The wells at Eagleport average about 700 feet in depth. The brine stands at about $7\frac{1}{2}$° B. as it comes from the wells. The brines grow stronger and wells deeper in descending the river. The brines at Eagleport are quite pure, yielding a small percentage of bitter water. A small percentage of iron is present, and is eliminated by a process peculiar to the locality, called the blood process of settling, and described under the Process of Manufacture in this chapter.

The Middle Kittanning coal furnishes fuel for the industry. The seam is worked above Eagleport near Zanesville, and the coal transported to the furnaces by boat. Slack coal is used when possible to secure it. At other times the furnaces use "mine run." They consume from six to eight tons daily each, and realize about three barrels of salt to the ton of coal. With the source of fuel so far removed, the weak brines and primitive process of manufacture, it is only a question of time till the salt industry will be a thing of the past in this valley. The salt produced is of fair quality, but lacking somewhat in uniformity. The product finds a market mainly in Zanesville and in small towns along the river.

Tuscarawas County.

The salt industry in this county is centered at Canal Dover. There are three furnaces in all, having a total daily capacity of 180 to 200 barrels. Bodey's furnace, owned and operated by Mr. C. W. Bodey, is located at Canal Dover. The Dover furnace, operated by Hilt & Shields, is located on the canal about two miles above town. The Goshen Salt Co.'s works are in the same locality, but across the river. The manufacture of salt was begun in this locality in 1865 and has been continuous ever since. A single well supplies the brine for each furnace. The wells have a depth varying from 850 to 900 feet. Some gas accompanies the brine, which, at the Dover furnace, is utilized for lighting purposes. The brines average about 10° B. as they come from the wells. The accompanying analysis shows their composition. They are quite impure, yielding a high percentage of bitter water. The impurities consist mainly of chlorides of lime and magnesia, with a notable percentage of bromides. Iodine is also present in sufficient quantity to pay for manufacturing, if a cheap process for its recovery can be determined. Iron and alumina are present in quantity sufficient to make the brines difficult to "settle". Bromine is manufactured from the bitter water and yields about one pound of bromine to each barrel of salt. The composition of the bitter water is also shown by the accompanying analysis. As this is nothing but the brine concentrated with the salt removed, the impurities are the same in character, but in larger proportions.

The furnaces are located on the outcrop of the Kittaning coals which are mined on the spot and either come directly to the furnaces or require to be hauled a short distance. From sixteen to twenty tons daily are consumed by each furnace, realizing about four barrels of salt to the ton of fuel. The furnaces are built substantially after the same pattern, using the steam and pan process combined in every case. The Dover salt has a wide and enviable reputation, the product being white and fine-grained, and equally adapted to table, dairy and packing purposes. No analyses were made of the commercial product. The accompanying analyses being made with a special object in view, as explained under head of Analyses, only show in a general way the purity of the product as marketed. The Tuscarawas Valley Salt Co., with offices at New Philadelphia, handles the entire product. The market is limited by competition with New York and Michigan salt from the north, and Pomeroy salt from the south. The product is all sold, however, at a fair price. The coarse salt is sold for glazing, salting hides, stock, etc., and, if pure, for packing purposes. The impure salt goes to the farmers for use as fertilizers.

Meigs County.

The production of salt in Meigs county is centered at Pomeroy. Four-fifths of the salt produced in the state is manufactured at this point. From the books of the Ohio River Salt Company it is found that the total product from August, 1885, to August, 1886, was about 400,000 barrels. The information is furnished through the kindness of Mr. George McQuigg, Secretary of the company. Salt has been manufactured at Pomeroy since 1850. The pioneer well in the territory is still being pumped, it now being the property of the Pomeroy Salt Company. Generally speaking, the Pomeroy district includes the salt manufactured on both sides the Ohio River at this point. The amount is about equal, there being six furnaces on the West Virginia side and seven furnaces on the Ohio side. The companies now active in Ohio, are as follows:

The Pomeroy Salt Company.
" Excelsior " "
" Coal Ridge " "
" White Rock " "
" Great Bend " "
" Buckeye " "
" Syracuse " "

All are located along the river above Pomeroy, with the exception of the Pomeroy Salt Company, which is located below. The furnaces of this district are built substantially after the same pattern. The steam process is used exclusively, the steam being produced from the salt-water itself, by heating in large boilers constructed for the purpose. The capacity of the furnaces is large, being, on an average, about 200 barrels per day. The brine from four wells is required at each furnace. The strength varies slightly with different wells, the average of the district being about 9 to 9½° B. The brines are quite impure, as the accompanying analysis shows, the chlorides of lime and magnesia being the largest impurities in amount. Sufficient iron is present in solution to require large settling capacity. The bromides and iodides are valuable impurities. About one-half pound of bromine is realized to the barrel of salt. As yet the iodine is not separated commercially.

The accompanying analysis of bitter-water shows the same impurities as the brines, but in larger amounts. Gas and oil accompany the brine from some wells in small amounts. No practical use is made of either.

The wells vary from 1,025 to 1,150 feet in depth, being deeper and

the brines stronger in ascending the river. The furnaces are located on the outcrop of the Pittsburgh coal, and the fuel comes directly from the mines to the furnaces. This seam carries about eighteen inches of "bone coal," of inferior quality, which would be a total loss to the mines could it not be utilized in the manufacture of salt. This quality of coal is brought to the furnaces at a nominal cost for mining. When navigation is closed the furnaces use mine run. The furnaces consume from thirty-five to forty-five tons of coal daily, and realize about five barrels of salt to the ton. The Pomeroy salt is widely and favorably known, the accompanying analyses showing it possible to manufacture salt of unusual purity. The salt, besides having a large sale for table, dairy and general use, is extensively used by packers. The latter is, perhaps, its largest use. It is preferred in the markets to the Michigan salt, with which it comes in competition for this purpose. A large amount of coarse salt is used along the river in the manufacture of glass, and as a material for glazing in pottery and sewer-pipe manufacture. The Ohio River Salt Company handle the bulk of the salt manufactured at this point. The principal markets are to the south, and down the river to Cincinnati, Louisville and St. Louis, where it is extensively used for packing purposes.

Geology.

For the geological horizons of salt-bearing strata in Ohio, see the review of the structure of the state in Chapter I of this volume.

History.

The history of salt manufacture in Ohio bears the stamp of a lost cause. Salt has been manufactured at various points since the early settlement of the state. Preceding the civil war, salt was being manufactured in moderate amounts in the Muskingum, Hocking and Ohio Valleys. New York stood first in the production, the Ohio and West Virginia District second, and a small product was manufactured in the Southern States. The manufacture in Michigan was just begun. During the war the importation of salt into southern ports was checked, and also the furnaces of the confederacy were mainly destroyed. Immediately succeeding the war there was a large market opened in the South, which had hitherto been supplied from other sources. A value was given to salt far above the cost of production. The business was inflated by war prices and large investments were made in developing new territory and erecting large and expensive furnaces. Large dividends were realized for a while, and the industry grew and flourished. In a few years, however, the old order of things was established again. Imported

salt found its way into southern markets and Michigan came promptly into the field with a large product. The price of salt was depressed below living rates,, and a view of the industry to day presents a scene of the "survival of the fittest." Only those localities are holding out that possess some special advantage in the way of strong brine, cheap fuel, easy transportation or valuable bitter water. Ruined furnaces are to be seen in every district. The Hocking Valley region, which, in its palmiest days, produced 50,000 barrels per annum, is entirely abandoned. The last furnace in the district which supplied a local trade being abandoned about a year ago. The Cambridge and Muskingum Valley fields bear the same stamp. These two fields, producing at one time an annual product of 80,000 barrels, are now represented by a few small furnaces supplying a local trade. The Dover and Pomeroy fields have shown more vitality. These localities are favored by cheap fuel and valuable bitter water, the Pomeroy field being favored by cheap river transportation to large markets. But in these localities even those furnaces less favorably located are abandoned. At Pomeroy, seven furnaces remain, where thirteen flourished soon after the war. At various other points in Ohio, abandoned furnaces remain as relics of a past industry.

The cause of this decline has been the rapid development and enormous production of the Michigan field, and later the development of rich fields in western New York. The advantage that Michigan possesses is an extremely strong brine. Ohio coal can be shipped to Michigan and salt manufactured as cheaply as in Ohio, where the furnace is located at the entrance to the mine. The St. Clair River district in Michigan is an example of this practice. This new and rapidly developing field, it is estimated, will produce one-half million barrels of salt the present season. The fuel used in this district is Ohio coal exclusively. On this the manufacturers must bear the cost of transportation and handling, in addition to the expense of mining, royalty and profit to the operators. Coal laid down at the furnaces in this district is worth from $1.80 to $2.00 per ton. Coal at the furnaces of the Pomeroy district does not cost to exceed sixty or seventy cents per ton. With these figures to work on, it is safe to say that the St. Clair companies lay salt on the docks as cheap as Pomeroy for the single item of fuel alone. The explanation of this is that the St. Clair brines are saturated, or nearly so. The Ohio brines are less than forty per cent. saturated. As a result the St. Clair brines deposit sixty per cent. of their salt with the fuel necessary to bring the Ohio brines to saturation. The average at Pomeroy is about five barrels of salt to the ton of fuel, while the St. Clair people realize fifteen barrels. The same is true in western New York, at Warsaw, where a saturated brine is secured from a rock-salt deposit. There is some comfort in the

fact that in the absence of strong brines, Ohio can yet furnish fuel. In the Saginaw Valley, the greatest salt producing centre in Michigan, as the saw mills with which the salt blocks are connected are being abandoned, the salt industry is being reclaimed with coal as a fuel. As the lumber industry dies in this locality, Ohio coal promises to be the future fuel for carrying on the salt industry.

The enormous production in Michigan is a second cause for depression in Ohio. From good authority the estimated product in Michigan the present season will approach four and one-half million barrels. This product will supply the markets of the west and northwest, leaving a surplus of nearly one million barrels to be disposed of elsewhere. This is shipped toward Ohio and New York, and sold for what it will bring. Ohio markets are thus made the "dumping ground" for the surplus in Michigan, nine-tenths of the product in Michigan being handled by the Michigan Salt Association. They maintain prices in the west, demoralize them in Ohio, and average the sales monthly, netting a fair average price for Michigan manufacturers but one which is ruinous to the industry in Ohio. There is a large product in western New York also seeking a western market. The eastern market being cut short by imported salt, Ohio is again the battle-ground between New York and Michigan interests, and Ohio manufacturers the sufferers.

The Strength of Brines.

Two instruments are in general use for determining the strength of brines—the salinometer and Beaume's hydrometer. The salinometer is used exclusively in Michigan, while Beaume's hydrometer is more generally used in Ohio. The following table is self-explanatory, and will serve as a ready means of converting the reading of one instrument into terms of the other, showing at the same time the per cent. of salt present in a pure solution of salt and water for any reading. The presence of impurities will affect the reading slightly. As this percentage varies with different brines, it is impossible to give an exact factor for correction.

TABLE SHOWING THE PER CENT. OF SALT PRESENT FOR ANY READING OF THE SALINOMETER OR BEAUME HYDROMETER AT 65° FAHR.

Degrees salinometer.	Degrees Beaumé.	Per cent. of salt.	Degrees salinometer.	Degrees Beaumé.	Per cent. of salt.
1	.26	.26	51	13.26	13.11
2	.52	.51	52	13 52	13.36
3	.78	.77	53	13.78	13.62
4	1.04	1.03	54	14.04	13.88
5	1.30	1.28	55	14.30	14.13
6	1.56	1.54	56	14 56	14.39
7	1.82	1.80	57	14.82	14.65
8	2.08	2.06	58	15.08	14.91
9	2.34	2.31	59	15.34	15.16
10	2.60	2.57	60	15.60	15 43
11	2.86	2.83	61	15.86	15.68
12	3 12	3.08	62	16 12	15.93
13	3.38	3.34	63	16.38	16.19
14	3.64	3.60	64	16.64	16.45
15	3.90	3.85	65	16.90	16.70
16	4 16	4.11	66	17.16	16.96
17	4 42	4.37	67	17.42	17.22
18	4.68	4.63	68	17.68	17.48
19	4.94	4 88	69	17.94	17.73
20	5.20	5.14	70	18.20	17.99
21	5.46	5.40	71	18.46	18 25
22	5 72	5.65	72	18.72	18.50
23	5.98	5.91	73	18.98	18.76
24	6.24	6.17	74	19.24	19.02
25	6 50	6.42	75	19 50	19.27
26	6.76	6.68	76	19.76	19.53
27	7.02	6.94	77	20.02	19.79
28	7.28	7.20	78	20.28	20.05
29	7.54	7.45	79	20.54	20.30
30	7.80	7.71	80	20.80	20.56
31	8 06	7.97	81	21.06	20.82
32	8.32	8.22	82	21.32	21.07
33	8.58	8.48	83	21.58	21.33
34	8 84	8.74	84	21.84	21 59
35	9.10	8.99	85	22.10	21.84
36	9 36	9.25	86	22.36	22.10
37	9 62	9.51	87	22.62	22.36
38	9 88	9.77	88	22.88	22 62
39	10.14	10.02	89	23.14	22.87
40	10 40	10.28	90	23 40	23.13
41	10.66	10.54	91	23 66	23.39
42	10.92	10.79	92	23.92	23.64
43	11.18	11.05	93	24.18	23 90
44	11.44	11.31	94	24.44	24.16
45	11.70	11.56	95	24.70	24 41
46	11.96	11 82	96	24 96	24 67
47	12.22	12 08	97	25.22	24.93
48	12.48	12.34	98	25.48	25.19
49	12.74	12.59	99	25.74	25.44
50	13.00	12.85	100	26.00	25.70

ANALYSES.

Analyses of Salt.	Canal Dover.		Pomeroy.	
	No. 1.	No. 2.	No. 1.	No. 2.
Moisture	8.050	16.170	2.800	7.680
Chloride of calcium	1.714	5.230	.585	2.700
Chloride of magnesium	.807	2.346	.256	1.095
Silica and iron	Trace.	Trace.	Trace.	Trace.
Chloride of sodium	89.429	76.254	96.359	88.525

Nos. 1 and 2, from Dover furnace, Canal Dover.
Nos. 1 and 2, from Coal Ridge furnace, Pomeroy, O.
No. 1, is salt first precipitated in each case.

The above samples were taken and analyses made with the idea of determining the difference in amount of impurities between the salt precipitated when the pans or grainers are newly filled and that precipitated just before the bitter water is drawn off. In the Dover samples the impurities in sample No. 2 are over three times, and in the Pomeroy samples over four times as much as in No. 1. The danger of impurities going into the salt by evaporating the bitter water too close, is eminently confirmed by these analyses. The chlorides of lime and magnesia being highly deliquescent bodies, their presence has the tendency of making the salt attract moisture and spoil the cooperage.

BRINE AND BITTER WATER ANALYSES.

	No. 1.	No. 2.	No. 3.	No. 4.
Specific gravity	1.0732	1.0713	1.317	1.307
Water	89.545	90.472	55.360	69.000
Total solids	10.455	9 528	44.640	31.000

COMPOSITION OF TOTAL SOLIDS.

	No. 1.	No. 2.	No. 3.	No. 4.
Sodium chloride	71.645	79.273	30.128	7.603
Calcium chloride	18.665	14.397	48.969	64.810
Magnesium chloride	9 286	6.097	20.201	27.013
Magnesium bromide	.271	.097	.592	.429
Sodium iodide	.013	.012	.024	.037
Silica	.024	.043	.032	.039
Iron and alumina	.096	.082	.054	.069

No. 1. Brine from Dover furnace, Canal Dover.
No. 2. Brine from Coal Ridge furnace, Pomeroy.
No. 3. Bitter water, Dover furnace.
No. 4. Bitter water, Coal Ridge furnace.

The absence of sulphates from the Ohio brines is remarkable. They differ from the Michigan brines in this respect. The presence of iodine in appreciable amounts is a fact, I believe, not hitherto reported.

The following process is offered as a means for the commercial separation of iodine contained in bitter water. The process is based on the following reactions: If to a solution of alkaline chlorides, bromides and iodides or to bitter water which contains a mixture of the chlorides, bromides and iodides of the alkalies and alkaline earths, a small amount of perchloride or persulphate of iron in solution be added and the liquid boiled for a minute, the iodine is liberated and readily distinguished by the violet color of its vapor. Chlorine and bromine are not liberated under these conditions. The process was employed in the laboratory for the detection and estimation of iodine as follows: 200 cc. of bitter water was placed in a flask, and about three grams of sesquichloride of iron in solution was added. The contents of the flask were then boiled and the liberated iodine vapors collected by passing through U tubes containing a solution of caustic potash. The iodine was subsequently determined in the caustic potash solution by gravimetric methods. I see no reason why the above process given in miniature could not be carried out on a large scale in connection with the regular manufacture of bromine, as follows: When the bromine still is being newly filled with bitter water, add about one-half pound of per chloride (sesquichloride) or persulphate of iron previously dissolved in water. Let the addition be made in such a manner that the iron solution will mix thoroughly with the contents of the still. Then turn on the steam and boil the contents of the still for a few minutes. The iodine would

be liberated, and passing off as a vapor could be collected by passing into a bottle or carboy containing a solution of caustic potash. When the potash would absorb no more iodine, it could be evaporated, crystallized and sold as crude iodide of potassium. After the iodine has all been liberated, then add sulphuric acid, and proceed with the distillation of bromine in the usual way. Persulphate of iron could be prepared at the works very cheaply, by puchasing common green vitriol, dissolving in water and oxidizing to the ferric state, by adding a little bromine water (red water) and keeping in a warm place for some hours before using.

PROCESS OF MANUFACTURE.

The process of manufacture will be described under the following heads:

Settling of the brines.
Evaporation of the brines.
Graining.
Lifting, drying and storing.

Settling.

The process of settling effects the removal of the iron and alumina' by allowing the iron to oxidize and settle, either by its own gravity or by addition of a small amount of caustic lime. This is accomplished by allowing the brine to stand in large open vats for some time. The settlers vary in size and shape considerably. As usually constructed, they are built of heavy three-inch plank, well keyed together and calked, being mounted on piles to such a height as to allow the settled brine to flow to the pan or grainers. They are built from four to six feet deep, and of any length and width desirable. The settlers are frequently heated by steam-pipes passing through them. The heat assists in oxidation and settling, and aids in concentrating as well. The use of caustic lime should be avoided as much as possible, as any excess stays with the brine and is precipitated with the salt more or less in the process of graining.

In the Muskingum Valley and elsewhere, where the kettle-process is used, the final removal of the iron is effected by the aid of beef's blood. The iron is partially oxidized by allowing the brine to stand exposed in the settlers for a time. It then goes to the kettles and is boiled till the solution becomes saturated and salt begins to deposit. The kettle is then chilled by throwing in a bucket full of cold brine, and about one-half pint of beef's blood is added. When the kettle boils again the blood coagulates, and collecting mechanically the small parti-

cles of iron aside, rises to the surface and is skimmed off and thrown away. While great claims are made for this process, there can be no possible reason why the iron removed in this way should make the salt any better than were it removed by some other process.

Concentration.

The brines are concentrated by evaporating in kettles—in large pans or large shallow vats with steam-pipes passing through them. These different modes of treatment characterize the kettle, pan and steam process, respectively. In Ohio, the steam process is often combined with the pan or kettle.

The Kettle Process.

In the kettle process, the evaporating is done in large iron kettles containing about 100 gallons each. The kettles are arranged in a double row, supported by arches, with flue beneath, fire-grate in front, and smoke-stack at the end. Usually there is a pan-heater or boiler immediately over the fireplace. The kettles are filled from a pump-log at one side, the pump log being connected with the heater or settler. The kettles are filled full—boiled to saturation—settled with beef's blood, and then run down nearly to dryness and the salt "lifted" out. This process is the oldest and least economical, being the practice in the Muskingum Valley. The furnaces have from twenty-five to thirty kettles each, and produce about three barrels of salt to the ton of fuel.

The Steam Process.

In the steam process the concentration is done in large shallow vats. The heat is furnished by steam-pipes passing through them. The settlers have already been described in full under the head of Settling. The grainers are usually 150 to 180 feet long, seven (7) feet wide and sixteen (16) inches deep. They are built of three-inch plank, well keyed and calked. They have three or four steam-pipes passing lengthwise through them, and raised from four to six inches from the bottom. At Pomeroy the pipes are made of copper, and are three or four inches in diameter. The steam is furnished by boiling the brine itself in large tank-boilers constructed for the purpose. The steam is conducted from the boilers to the settlers and grainers through pump-logs. The use of iron pipes is avoided on account of the tendency to rust. The boilers cannot well be described in detail without the aid of drawings. As usually constructed, they are large iron pans, built in sections, about ten inches deep, with a wooden box cover made of plank, keyed and

calked, being rectangular, about four feet deep, eight feet wide, and thirty feet long. Four or five of these boilers are placed end to end, having a common fire-box in front, flue beneath and stack at the end. This arrangement constitutes the furnace proper. The brine being partially concentrated in the boiler, passes to the settlers, thence to the grainers. The steam from the first concentration is thus made to complete the operation. This process is employed exclusively at Pomeroy. Considering the brines to be worked and fuel at hand, it is probably as economical as any method that is practicable in this locality.

The Pan Process.

The pan process alone is not used anywhere in Ohio. At Canal Dover the steam and pan process is combined. The boilers and settlers are similar in construction to those employed in the steam process. The pan takes the place of the grainers, the brines being concentrated to saturation in the settlers. The pans are built of three-sixteenths inch boiler-plate, riveted. They are forty to sixty feet in length, eight to ten feet in width, and ten to twelve inches in depth. They are placed over the flue next to the stack, the boiler being placed over the fireplace. It is necessary that the salt be "lifted" often from the pans, else the salt will collect on the bottom and the pans burn.

The special advantages of the pan are noticed in the next section.

Graining.

As noticed before, the graining is carried on in kettles, pans or large wooden grainers. The "grain" of the salt is regulated in two ways, viz., by variation in the temperature at which the graining is done, and by adding to the kettles, pans or grainers a small amount of rosin or grease. The lower the temperature at which the salt crystals form, the larger they will be, and vice versa. When the furnaces close down for Sunday, a "dip" of coarse salt is the result on Monday morning, due to cooling of the pans and grainers.

The addition of a small amount of rosin or grease has the effect of making the salt crystals smaller and settle soon after formed. Butter or lard is more commonly used for this purpose. It is easy to understand then, that in the pan process the grain can be regulated by firing. But in the steam process the use of grease is necessary if a fine grain of salt is desired. The practice is objectionable, for the reason that a small amount of the grease must necessarily go down with the salt, making an undesirable impurity for table or dairy use. The very fine table salt of commerce is mostly made by drying coarse salt and grinding.

Lifting, Drying and Storing.

In the steam process the salt collects in the grainers and is lifted once in twenty four hours. This is usually done in the morning. The salt is raked together and shoveled upon the drying boards above the grainers. Here it is allowed to remain for several hours to allow the excess of bitter water to drain out. It is then wheeled away to the storeroom and piled in large bins. It is allowed to remain here for several weeks before packing. During this time the moisture and last traces of bitter water drain out. It is then packed in barrels of 280 pounds each and is ready for the market. In the pan process, as noticed before, it is necessary to lift the salt more frequently. A hanging table is constructed above the pan; the salt is placed on this and allowed to drain, then removed to the bins for storage.

From the process of manufacture described, it is evident that the quality of the salt will be variable, the salt first precipitated being pure, while that last precipitated contains a high per cent. of impurity. There being no law to regulate the manufacture, it lies entirely with the manufacturer as to how close he shall "run" his bitter water or how impure his salt shall be. The industry being hard pushed by competition from elsewhere, the tendency is to make as impure a salt as will sell. The states of Michigan and New York recognize this evil and provide rigid inspection laws regulating the manufacture. While the law is a light burden on the industry, the reputation of the salt is maintained and honest manufacturers are protected against their more greedy but less honest neighbors.

Bromine Manufacture.

Ohio is the first state in the Union in the production of bromine. Canal Dover and Pomeroy are the two centres of production. It is the thread by which the salt industry has hung in these localities. The total product in the United States is pooled at present, and it is impossible to secure absolute data as to the amount produced in Ohio. The product at Canal Dover is about six pounds of bromine to every seven barrels of salt, and at Pomeroy a little less than one half pound of bromine to one barrel of salt. Making an estimate on this basis and we have for the production of the current year.

Canal Dover	55,000 pounds.
Pomeroy	166,000 "
Total	221,000 pounds.

It is probable that the estimate is a little high, as the stills get out of repair occasionally.

The production in other states is about as follows:

West Virginia	100,000 pounds.
Pennsylvania	100,000 "
Michigan	60,000 "
Total	260,000 pounds.
	221,000 "
Total for the United States	481,000 pounds.

Canal Dover.

Mr. C. W. Bodey is the pioneer in the manufacture of bromine at Canal Dover. Mr. Bodey was sent out as chemist by Rosengarten & Sons, of Philadelphia, Pennsylvania, to Tarentum, Pennsylvania, in 1886. He came to Canal Dover soon after. The Dover bitterns are the richest in the state. Each furnace in this district runs a bromine still in connection with its salt plant.

Pomeroy.

Mr. Gustave Ajgerman was the pioneer in the bromine industry at Pomeroy, having begun the manufacture in 1868 at the Dabney works now abandoned. At present the United States Chemical Co. purchase the bitterns from the salt furnaces with one exception. The company maintain a still at each furnace and the bitterns are worked up daily.

Bromine—History and Uses.

Bromine is one of the rarer elements of nature. It is a dark-red liquid at ordinary temperature, easily volatile, and giving off red fumes on exposure to the air. It has a density of 2.976. It is closely allied to chlorine and iodine in its chemical reactions. It was first manufactured in this country at Freeport, Pennsylvania, in 1846. Its only use at that time was in photography in the old Daguerreotype process In 1866 the value of potassium bromide as a nervous sedative was demonstrated. This gave an increased demand for bromine, and brought the pioneers of the industry from Pennsylvania to Ohio, where its production has been steadily maintained. It occurs in our brines as bromide of magnesia, which is an extremely soluble salt, and remains in solution in the bitter water after the salt is eliminated. The product is shipped from the works in six-pound bottles. It goes largely to manufacturing chemists. A large amount is exported annually. The price has declined since 1846 from $6.00 per pound to thirty-three cents, at which price it is now held. It is used extensively in medicine and photography, the bromides of potassium, sodium and ammonium being nervous sedatives of great value.

Process of Manufacture.

The process of manufacturing is as follows:

The bitterns are concentrated to 35° to 45° B. The stills are then filled to the funnel (see drawing), and sulphuric acid equivalent to the bromine present is added through the funnel (D). The contents of the still are then heated by turning on the steam at the bottom. Binoxide of manganese is now added in small amounts through the funnel for that purpose. This funnel extends some distance into the contents of the still. The bromine is liberated as a gas, and condensed in the leaden pipes as it goes through the condenser. The glass jar collects the bromine as a liquid. A slight excess of chlorine is liberated in the process, which will not condense. To provide for this, and also a small amount of bromine that does not readily condense, a return pipe leads from the jars again through the condenser, and into a second jar. This jar collects the remaining bromine. From this jar, a pipe leads to a charcoal tower (a couple of lengths of sewer pipe filled with charcoal and wet with bitter water) which absorbs the chlorine liberated in excess, and which would otherwise escape into the air and poison the workmen. Chlorate of potash is sometimes used instead of binoxide of manganese. The proportions of manganese to sulphuric acid are as one to two (1 $Mn\ O_2$ to 2 $H_1\ SO_4$). When chlorate of potassium is used, the proportions are one to four (1 $K\ Cl\ O_3$ to 4 $H_2\ SO_4$). The refuse liquors from the bromine stills are utilized in the manufacture of chloride of calcium. The excess of acid present is neutralized with caustic lime and the liquors concentrated till the chloride of lime crystallizes out. A large amount of this product is manufactured annually at Pomeroy. Chloride of lime is an extremely deliquescent body, and is used extensively as a dryer in cellars and storehouses for preserving fruit, where a dry atmosphere is desired. It is also used as a high temperature bath in fruit canning establishments, melted chloride of lime boiling at 350° Fahrenheit. It is used also in the manufacture of artificial stone (Ransom's patent), and in the manufacture of ice in the south. It is an open question if these liquors could not be utilized in the manufacture of a commercial fertilizer of high value.

The Still.

The still is solid sandstone of the best quality. The walls are six inches thick. The cover is made separate, and luted to the base with beeswax. Two fire-clay funnels are set in the top, one for the introduction of sulphuric acid, the other for binoxide of manganese. A steam jet is inserted at the bottom for heating. The steam is blown directly into

the contents of the still. A second opening is made at the bottom for emptying the contents of the still after the bromine is extracted. The condenser is simply a wooden box into which cold water enters. The bromine condenses from vapor to a liquid in passing through. The extra bromine jar and charcoal tower have been already mentioned.

CHAPTER XIII.

NATURAL AND ARTIFICIAL CEMENTS.

By Professor N. W. Lord, Ohio State University.

Cements, as considered in this chapter, embrace those materials obtained by burning or calcining certain rocks or mixtures of clay and limestone, slag, etc., and which, when mixed with sand and water to a mortar, "set," or harden, without exposure to air. They all have lime as the basis of their composition, but the mortars they furnish differ from ordinary lime mortars in having less plasticity, as a rule, and in this property of hardening and not disintegrating under water. Cements are more and more replacing ordinary lime in the construction of all masonry where strength and durability are desired.

Even where lime mortar is used, as for ordinary brick-work, it is becoming customary to mix with it a certain proportion of cement. It is claimed by Gillmore, and other writers, that the cement so added is useless, but many excellent masons and contractors so use it, stating that it gives greater body to the mortar and prevents any settling of the interior of the work. The lighter-burned natural cements are used for this purpose, and, as many of these contain an excess of clay and magnesia, they possibly act upon the free lime in the mortar, hardening it in a way that the artificial cements would not do.

Cement rocks, after burning, do not "slack," or fall to powder when wet with water, but require to be ground in mills before using. They are thus distinguished from certain "hydraulic limes" which, after slacking in the usual way, furnish mortars setting under water more or less powerful. Magnesian limestones belong to this class. They slack slowly, developing little heat, and furnish mortars which are decidedly hydraulic. The magnesia, probably, acts by gradually crystallizing as a hydrate. As an experiment, a mortar was made of pure calcined magnesia and sand. In a few hours it set hard enough to be handled, and was put in water. It retained its shape, and while not getting very strong, it gradually hardened like a true cement. From this it would seem that in a magnesia lime mortar, this setting of the

magnesia would account for the resistance to water, as it would prevent disintegration while the enclosed lime would gradually become carbonated and give strength.

Rocks which make cement by burning are very generally distributed, but, as a rule, the deposits are marked by great variability in quality. Of two layers in a quarry, one may be cement rock and the next a worthless shale; and even the same layer may, in a short distance, entirely change its character. From this cause, in part at least, the various attempts to work the smaller and more common deposits have more or less generally failed, and the natural cement of the market is obtained from only a few localities where large deposits of tolerably uniform rock occur. Of these, the two which furnish by far the larger part of the cement of the United States are Ulster county, New York, producing the Rosendale cements, and Louisville, Kentucky, from which are shipped the numerous brands of "Louisville cement."

The rock is, in both places, a shaly limestone. In New York, it lies between the Lower Helderberg and Niagara groups; and in Kentucky, on top of the Corniferous limestone, corresponding exactly to the beds covering the limestone at Columbus, Ohio. The total production of natural cement in the United States in 1883 was estimated at 4,100,000 barrels of 300 pounds (Mineral Resources of the United States, Albert Williams, Jr.,) of which Ulster county, New York, furnished nearly one-half, and Louisville by far the larger part of the remainder.

Many of the impure limestones and shales of Ohio would furnish excellent cement when properly burned. Such are some of the magnesian limestones near Sandusky, a number of the Carboniferous limestones, the shales over and including top of the Corniferous. The Black (Huron) shale, where it lies over the limestone is, for the first fifteen or twenty feet, quite calcareous in some localities, and in such cases furnishes an excellent cement rock.

The efforts to make cement on a large scale from these various materials have not been very successful, probably from failure to understand the irregularity of the deposits and want of capital to duly press the enterprise. Works were started at Sandusky, but they did not continue. One of the most promising ventures in this direction was at Defiance, in the northwestern part of the state where Mr. E. H. Gleason manufactured the "Aug'aize Cement" from the lower and most calcareous layers of the Huron shale. The cement was of excellent quality, and it is hard to account for the non-continuance of the works.

In the southeastern part of the state, cement has been, and still is, made at a number of points, the materials being the impure limestones of the Coal Measures. The cement used in the railroad bridge at Beliaire

was made by T. C. Parker & Sons, at Barnesville, Belmont county, from the cement limestone lying between the Pittsburgh and Meigs Creek coals (coals Nos. 8 and 9.) At Barnesville, the stone is five feet five inches thick, and was mined by drifting. These works are no longer in operation. The works just below Bellaire are now making cement from the same stone, which is drifted for in the hills. The stone is burned by mixing it with coal slack and running through a kiln. It is then ground in buhrs and barreled. Near New Lisbon, in Columbiana county, also, cement is made from a similar limestone which belongs to the Lower Freeport horizon. These are the only attempts that have been made to work the Ohio material on a commercial scale.

It thus appears that the rocks which yield cement on burning are invariably more or less impure, that is, silicious limestones, and in most cases strongly magnesian, though in some of the best foreign cements this element is nearly absent. To illustrate this composition more fully, the following analyses are added, some of them made by the writer, and others gathered from various publications.

AMERICAN CEMENT ROCKS.

	1	2	3	4	5
Carbonate of lime	30.72	41.80	69.00	42.25	46.52
Carbonate of magnesia	35.10	8.60	3.40	31.98	26.40
Silica	19.64	24.74	15.65	.....	16.41
Alumina	7.52	16.74	6.80	22.18	5.44
Oxide of iron	2.38	6.30	2.50	undet.	3.38
Alkali	4.10	6.18	undet.	undet.	undet.

1. Ulster county, New York.
2. Cumberland, Maryland.
3. New Lisbon, Ohio.
4. La Salle, Illinois.
5. Bellaire, Ohio. (3 and 5 analyzed by the writer).

American Cements.

	1	2	3	4
Silica	22.73	17.17	24.40	22.70
Lime	34.54	48.28	41.80	36.31
Magnesia	21.85	19.13	16.29	25.72
Oxide of iron and alumina	10.43	10.80	6.20	7.40
Alkali	3.63	trace.	1.52	undet.
Water, carbonic acid and loss			9.89	4.00

1. Rosendale cement.
2. Rosendale, another make.
3. Louisville cement (analyzed by writer).
4. Buffalo Natural Portland (analyzed by writer).

Where analyses of cement or cement rock do not give the amount of the alkalies, they must be regarded as incomplete. Gillmore says in his book on "Limes, Hydraulic Cements and Mortars" that all cement rocks contain alkalies, which are important in determining their cement-forming qualities. It is also known that in the manufacture of Portland cement from a mixture of clay and limestone a certain per cent. of alkali if not present in these materials, must be added. The amount is small, but it is essential.

The causes of the setting of a cement have been much discussed and a number of theories devised. Probably no one cause explains all that happens, and it may be that different cements bring into action different chemical actions; but for practical purposes, the following points may be considered as established, and as they have direct bearing upon the recognition and treatment of cement rocks, it will be necessary to discuss them in some detail.

In the first place, the principal constituent of all these rocks is lime. There can be no cement made from any shale, clay, or slate, alone, which does not contain this element in excess of others; and as the lime always occurs as carbonate, it is evident that the greater part of all such substances will be dissolved by warm, dilute muriatic acid. There will be, in all cases, a residue left undissolved by the acid, which is very fine and not sandy, and when separated and washed, is found to be like very fine clay. It contains the silica and almost all of the alumina of the stone but only a trace of the lime, that having been taken out by the acid. This clay-like character of the residue is characteristic of the cement limestones. Those which have a sandy, gritty residue, will have

no hydraulic properties when burned, even though the amount of such residue be considerable. This constitutes an easy approximate test for cement stone. When pulverized, it must dissolve in warm muriatic acid, giving a muddy liquid, the more residue the better, if it is not sandy and gritty.

After such a rock is burned at a bright red heat for some hours, it changes entirely in character. When powdered, it dissolves entirely or nearly so in acid, giving an almost clear liquid; and in the solution will be found the silica and the alumina of the stone. Chemistry shows that in this case the silica and alumina were combined with lime, while in the original clay residue, they were combined with each other in the clay. Therefore, a cement contains silicate and aluminate of lime. These compounds absorb water, uniting with it to form hard, crystalline minerals. Evidently this, then, is part of the action of the "setting." The extent to which this formation of aluminate and silicate takes place in the burning probably depends upon the stone used. It certainly does not have to be complete. If a clay containing some free lime be strongly burned, so as to cause a partial combination between it and the alumina and silica, and then, after finely pulverizing, be mixed with ordinary slaked lime, this mixture will "set," and the resulting mass contains crystalline hydro-silicates, exactly as in the case of a cement. Again, if some cement rocks be heated to the point where complete combination occurs, the mass may melt and give a hard, glassy "slag," having no cement properties whatever.

What the small amount of alkali has to do with the setting, it is difficult to state. It may aid in promoting the combination during burning, and it may also make the silicate formed more easily attacked by water, and so facilitate the hydration, or finally, it may act to transfer silica to lime, forming silicate of potash, which is continually decomposed by the lime.

A cement rock, then, consists of a limestone, either magnesian or not, having intimately mixed with it fifteen to thirty-five per cent. of clay, and a little potash or soda. The hydraulic energy given to such a rock by burning will vary with the temperature and length of time it is heated. Where it is burned too hard, it may, as before stated, lose entirely its property of setting, forming even a slag-like mass like the furnace cinder in iron-making. This danger of over-burning is probably greater in the more magnesian stones, as it is well known that lime and magnesia form a more fusible combination with silica than either alone. This may be the reason that, while the artificial cements, having about the same composition as the natural ones, except that they contain only lime, are best and strongest when highly burned, the others are

only able to stand a limited burning without becoming vitrified and ruined.

From the table of analyses given before, the composition of an average cement rock may be stated to be—

Carbonates of lime and magnesia	75 to 60 per cent.
Silica	15 to 25 " "
Alumina	6 to 12 " "

and it may be expected that any one having a composition between these limits will probably furnish a cement when calcined for a certain time at a certain temperature, points which may be ascertained by experiment. Gillmore gives full directions in his work before referred to for ascertaining the proper degree of calcination. His method is essentially as follows:

The stone, after breaking into pieces of approximately the same size, which should be about as large as a walnut, is placed in a large fire-clay crucible provided with a hole in the bottom, like an ordinary flower-pot. This hole serves to permit a current of air to pass up through the crucible and thus assist the calcination of the stone. The crucible with its contents is then placed in a good coke-fire (best in a large grate) and heated to bright redness. After forty-five minutes, a few pieces are removed, and again after an additional forty-five minutes, some others, and so on at intervals of three-quarters of an hour, until some have been heated for at least six hours. These various fragments are separately ground to powder, and made into a stiff paste with water. The time and energy of setting together with the subsequent behavior in water, will indicate the quality of the stone as developed at each degree of burning.

Limestones, of course, slack and fall to powder. The slightly hydraulic limes will set and hold their shape when very lightly burned, but the longer heated portions crack and disintegrate. The true cements set and gradually harden under water, though those portions hardest burned may lose their value. Where the greatest strength is developed by a moderate burn, the cement will be found to set rapidly, as a rule.

There are some cements, which, as the temperature and time of burning increase, become slower-setting and stronger. Such a rock may furnish two kinds of cement, a quick-setting, light-burned, and a slower-setting, heavier burned, the latter resembling the artificial Portland cement. The "Buffalo" cement rock is of this character; and the burned stone from the kiln is partially pulverized, then separated into powder, constituting the light cement and hard lumps, which, being heavier burned, resist the first grinding. These, subsequently ground again, furnish the "Buffalo Portland" cement.

The preparation of the cement on a large scale is simply the application of proper machinery for doing in a cheap and efficient manner the same thing that was described before in the laboratory testing of the rock, the two steps being a careful burning of the rock and its subsequent pulverization. The goodness of the resulting material will, however, largely depend upon the skill with which these operations are performed. The proper temperature being ascertained for the burning of the particular rock, it must be carefully maintained by regulating the amount of fuel, and in the product drawn from the kiln, all under-burned or over-burned parts being separated by the workmen before it goes to the mills.

The pulverization is one of the most important points. It has been found by careful experiment that the coarser particles of the ground cement are of no more value than so much admixed sand, only the finest powder having the power of setting; and as the cement is always used in mortar with sand, it is evident that the more of the material which is in the dusty state, the more sand the cement will carry to make a mortar of a given strength. Hence, in testing a cement prepared for use, it should be sifted through a very fine sieve, and the amount of coarse ground material noted. The smaller this is, the better.

The kilns used in burning are oval or round in section, and from twenty-five to forty-five feet in height. They are contracted toward the bottom, and are there provided with arched openings through which the burned stone is drawn. The shell or support of the kiln is masonry or sheet-iron, as in the case of blast-furnaces. The natural cement rocks are usually burned "continuously," that is, the material is continually added at the top as it settles in the furnace, and is drawn at small intervals from the bottom. This plan, of course, takes less fuel than where a kiln full of material is allowed to cool, and then a fresh one heated. This latter plan, however, seems to be preferred in burning the artificial cements.

The fuel is, in many cases, mixed with the stone and the whole burned together, coal slack or small coke being used. In other kilns, there are furnaces at the sides in which wood, coal or coke can be burned, and the hot flames then pass into the body of the stack, heating the stone thus kept from direct contact with the fuel. This plan has one great advantage. As the temperature and extent of burning will be regulated by the rapidity with which the material is drawn from the bottom, the faster the stone is taken out, the more rapidly it passes through the kiln, and the less it will be burned.

Where the fuel is mixed with the stone, the heat will be regulated by the proportion added. This must be determined by experiment;

and should a variation in the quality of the rock necessitate a change in the temperature, it can only be learned when the kiln has burned through, and when it is too late to correct the damage, while in the former class of furnaces, the burner simply changes the rate of drawing, and so raises or lowers the heat, as the appearance of the clinker indicates.

At the Utica mills, described in the "Transactions of the American Institute of Mining Engineers," vol. 13, where four kilns with side furnaces are used, the largest having a capacity of 1,000 barrels, the drawing is done every two hours, the material being in the kiln four days.

To ascertain the quality of the rock, a small "try kiln" a couple of feet square and six or eight feet high is used, and it should be kept running pretty constantly where the regulating of the burning depends ubon the varying of the fuel mixed with the rock, or an undetected change in the character of the stone may cause the loss of a kiln full of cement. A simple chemical expedient for controlling the character of the material would be the determination of the carbonic acid given off by a certain weight when dissolved in acid. This could be done on the stone as it came from the quarry, and any variation in the quality would appear at once. This method of control, when applied to the manufacture of artificial cement, has given perfect satisfaction in securing regularity of product, the mixture being tested three times daily.

The arrangements for handling the stone must be of the simplest and most efficient description. At one of the principal works at Louisville, the rock is quarried from a bed twenty feet thick which lies under five feet of soil and shale (stripping), is thrown into cars which are drawn by a wire rope up an inclined plane, and dumped into the top of the kiln with the requisite fuel. The kilns are in rows of four. The "clinker," or burned rock, is drawn from the bottom, as usual. One man will do the drawing for a large kiln. Where kilns of the side-furnace type are used, a man can fire one or two of them. As this work is necessarily continuous, double-turns, night and day, must be worked.

The kilns are lined with a single course of fire-brick, supported as previously stated, by masonry or an iron shell of No. 12 to 16 tank iron, with an intervening course of red brick and a space of two inches, more or less, filled with sand, loam, or ashes, to allow expansion. The kilns should face the prevailing winds to accelerate the draft.

The burned stone must be, as already noted, carefully picked over to remove under-burned or over-burned portions which are worse than merely useless, being in some cases dangerous to the quality of the cement, causing it to swell and crack, owing to their containing uncombined lime. The clinker is next crushed to the size of small gravel, the

finer the better, as crushing costs less than grinding, and the smaller the particles the less wear on the mill-stones. The usual apparatus for crushing is some sort of jaw-crusher. There are a number of patented machines of this class. All do good work. The special form most useful for a given rock would probably be determined by the hardness of the clinker produced. At the La Salle mill, in Illinois, the burned rock is crushed in a "dry pan," with a heavy roller similar to the apparatus used in working fire-clay for brick-making. This would, probably, only be adapted to a comparatively tender clinker. The grinding machinery is the most important about the mill. The machine almost universally used is the buhr-stone, set in all respects like a flour-mill, the stones commonly running horizontally, though in some mills they run vertically, the material being fed on top of the stones which are carried by a horizontal spindle. Such stones are run at high velocity, five hundred revolutions a minute. The engineer of the Utica mill states that a pair of thirty-inch vertical stones grind, at that velocity, fifteen barrels per hour. The yield will, of course, depend upon the hardness of the clinker. A pair of forty-eight-inch horizontal stones working on Portland cement clinker, will hardly average more than a third of the above amount, if the proper standard of fineness is maintained.

There have been numerous machines invented for fine pulverization of cement, and probably some of them are efficient; but thus far the buhr-stone has held its own, as giving the peculiarly dusty, impalpable powder which is absolutely necessary in this case. The great objection to the buhrs is their high cost for maintenance. The face, or "dress," rapidly wears off, and the mill has to be "hung up" and cut again every few days. The labor for this must be skilled, and the expense is a heavy charge.

The ground cement is run either directly into barrels, which are continually jarred on a "shaker," so as to settle the cement all down and prevent the barrel from settling when headed-up and shipped, which would be the case were the material simply run in; or else it is taken from the mill by elevators into bins for storage. The natural cements are probably best barreled directly, as they deteriorate on keeping; but the artificial cements must be aged in the bins awhile to give them a safe character.

The natural cements of the United States are generally rather quick-setting, that is, take a set in less than a half-hour, when tested "neat," or without sand. The "neat" cements usually show from sixty to a hundred pounds tensile strength on a section of one square inch, after seven days, when tested according to the standard method of the Society of Civil Engineers, described further on in this chapter. In good ce-

ments, the strength should continue to increase slowly, until at the end of a year, it should reach three hundred or four hundred pounds. Many, if not all, of the natural cements deteriorate on keeping, the free lime becoming carbonated and losing its power of acting upon the clay silicates of the burned rock. In this respect, such cements differ greatly from the artificial Portland cements, which, as will be seen, owe their peculiar value to the formation of silicates and aluminates of lime which are not readily altered by the action of air, and instead of deteriorating with age, improve steadily in value for two years at least, as these cements are better when the small amount of free lime they contain is slaked and its "cracking" tendency thus destroyed.

Artificial Cements.

The foregoing brief review of natural cements shows the wide variations in their composition and character, the want of uniformity of the product of even the same works, and the moderate strength which they generally possess. It has also been made apparent that the valuable properties of these "material cement rocks" are due to the admixture of calcined clay and caustic lime with silicates and aluminates of lime. These ingredients, occurring in widely different proportions in natural rocks, give various values to the stones, and need careful burning to develop the maximum power in the particular rock used. The discovery that a superior cement could be made artificially by the burning of a mixture of lime and clay was made early in this century, and is the subject of several English patents from 1810 on. It was the logical result of Smeaton's discovery that the limestones containing clay were the most hydraulic. John Smeaton, the Contractor of the Eddystone Light House, in searching for a proper mortar, made a remarkable series of experiments on the composition of limes, and is acknowledged to have been the first to discover the true cause of the difference in water resisting power of mortars ("Portland Cement, Its Manufacture and Uses," by Henry Reid). But for a long time the knowledge on the subject was largely empirical, and it has only been lately that the principles involved have been understood and the wide applicability of the methods appreciated. The manufacture of Portland cement was confined to England, where the chalk deposits furnished an abundant supply of easily disintegrated carbonates of lime, and for admixture, the soft and sandless alluvial clays of the Medway. The name of the artificial cement is given from its resemblance in color, when "set," to the famous Portland Stone of which Westminster Abbey is built.

Within the last few years, with more definite knowledge of the

combinations required in the making of Portland cement, the manufacture has spread all over the world, the greatly increased production hardly meeting, however, the demands created, as the superior quality of the artificial over the natural material has been more and more demonstrated. These advantages are uniform and high strength, indefinite keeping quality, and perfect hydraulicity, setting under water as strongly as in air.

The production of artificial cement has thus far been confined almost exclusively to the manufacture of this "Portland," or heavy and slow-setting cement. There appears to be no reason why a quick-setting and lighter cement should not be produced with equal facility, except that the excessive cheapness of the natural cements, which have these qualities, renders this artificial product unnecessary. Portland cement is now made in England, France, Germany, and very recently in one or two localities in the United States.

That the manufacture of Portland cement is certain to become a more and more important industry in this country is most obvious. The enormous increase of its importation during the last few years (58,450 barrels in 1877, and 456,362 barrels in 1884 having been received at the port of New York) shows the rapidly increasing rate of consumption, this increase of foreign purchase being in the face of a home production of 100,000 barrels in 1884 as against practically none in 1877 ("Mineral Resources of the United States"—Williams). This increase is due (Op. Cit.) to the rapidity with which cements are replacing lime mortars in all ordinary building work.

In view of these very significant facts, it would appear that the consideration of the facilities which the state of Ohio affords for this manufacture would be of great importance. That the manufacture of Portland cement has been so little undertaken is partly due to two facts, first, that there has been a wide-spread impression that some mysterious virtues in the English materials made the venture anywhere else "extra hazardous," and secondly, that the whole manufacture has been so little discussed and understood that anyone entering this field of investigation was treading new ground and could get little assistance from any published writings. The publication of Mr. Henry Reid's book on "The Manufacture of Portland Cement" put the whole art in the hands of the public; but still there is so much ignorance and prejudice that anything but English cement is looked upon as an imitation, in spite of the fact that considerably over half of the cement imported in 1884 did not come from England but from the Continent of Europe.

The principles involved in the manufacture are few and simple.

The practical application of them requires merely intelligence, some accurate chemical knowledge, and careful attention. The object to be attained is the production of a certain combination of lime, silica, alumina, and alkalies; and the method is simply by proper mechanical treatment to bring these elements into very intimate admixture, and then, by submitting them to the requisite heat, to cause their chemical combination.

The materials necessary for the production of Portland cement are very widely distributed, and may be of the most various kinds; but at least two classes are always required, first, a source of lime. This may be chalk, as in England, limestone, as in Ohio, or shell marls, which also occur in many places in this state. The limestone may contain clay, provided the deposit is uniform in quality, but should be as low as possible in magnesia, this element being injurious to Portland cement, which in this respect differs from the natural cements. The uniformity of quality in the limestone is a point of capital importance, as without it, it must be difficult to maintain the regularity of composition so necessary to the cement mixture. The softer and less crystalline the limestone, the more easily it can be brought to the impalpable powder necessary for its thorough admixture with the other elements of the charge. In the case of hard and crystalline limestones, it might be necessary to give them a preliminary burning to render them soft enough, but the writer has made first-class Portland cement from such rocks with no preliminary treatment whatever. There are plenty of limestones in Ohio which will answer the purposes of cement manufacture perfectly. Their great purity is shown by the following analyses:

	1	2	3	4	5	6
Carbonate of lime	94.18	94.19	87.25	96.80	92.02	95.10
Carbonate of magnesia	1.02	1.29	5.26	2.07	1.85	1.30
Silicious matter	2.23	4.25	5.80	0.83	2.90	3.60
Iron and alumina	1.26	0.26	1.30	0.29	2.71	0.6

1. Ames or Crinoidal limestone, Sunday Creek hills.
2. Upper Helderberg limestone, Columbus limestone, average of eight samples.
3. Upper Helderberg limestone, Columbus limestone, smooth rock.
4. Clinton limestone, New Carlisle.
5. Coal Measure limestone, Holmes county.
6. Maxville limestone, Perry county, hardpan of quarrymen.

It is desirable that the silicious matter, if in the form of sand, be as low as possible, as in this shape it is difficult to bring it into the proper combination. When it is clay-like in character its amount is not so important if it be accurately known and allowed for.

The shell marls are of frequent occurrence in Ohio, and where large deposits occur, they might easily be used for cement manufacture, their friable and soft nature rendering them peculiarly adaptable for this purpose. The following analysis illustrates their composition:

	1
Carbonate of lime	55.90
Carbonate of magnesia	1.90
Iron and alumina	7.40
Insoluble residue	31.30
Alkalies	2.49

1. Woodstock marl, Wormley.

The second class of materials required is that which furnishes silica, alumina and alkalies. This class comprises a great variety of substances. In Ohio, two great sources exist: First, clays. The extent and variety of clays in this state is very great, but not all are equally fitted for the manufacture of cement. The points to be considered are, however, those which govern the choice of limestone, that is, the mechanical condition of the silica the clay contains. The great secret of the proper manufacture is the intimate combination of the materials previous to burning. Hence, clays free from grit or sandy parts are essential, the hard grains of sand resisting pulverization almost absolutely. Therefore, "fat," or plastic, clays are those to be sought. The fusibility of the clay is, in the opinion of the writer, a point of importance. Clays which are not too refractory lend themselves to combination at a lower initial temperature than those freer from lime and alkalies. Hence, clays high in alkalies are those most desirable, and can be burned more regularly into a good "clinker," as the burned but unground cement is termed. The presence of a certain amount of alkali is also necessary in the cement itself, and hence, is all the more required in the clay. The higher the clay in silica, provided the silica is not present as sand, the better. Very aluminous clays seem harder to burn right, owing, possibly, as has been suggested by Reid, to the aluminates and silicates forming at different temperatures, so that unless

the silica preponderates considerably, the burning is likely to be wrong. In addition to clays, there are many shales, consisting of extremely fine silicious matter, and easily, especially after a preliminary burning, reduced to fine powder, which would yield very fine cements, if properly mixed and handled. Such is the black shale of this state, of which the following is an analysis:

Black Shale, Columbus, Ohio.

Silica	60.35
Iron and alumina	21.20
Carbonate of lime	2.95
Carbonate of magnesia	3.33
Volatile and organic matter	10.70
Moisture	0.70
	99.23

There is a most valuable material in furnace slag from coke furnaces. These slags contain from thirty-two to thirty-eight per cent. of silica combined with alumina and lime, the latter often forming forty-six to fifty per cent. of the slag. The silica is in such shape that it can be most easily made to combine with the extra lime needed. Many of these slags are already cements, and when powdered, will "set" to a hard rock, in time, if kept wet. In the use of furnace slag, two or three points need to be considered, however. In the first place, the presence of considerable sulphur in the material is invariable. This has a most injurious action on cement, and more than a few tenths of a per cent. will injure the strength and permanency. This sulphur can be partly removed by running the hot slag into water, thus "granulating" it, a most desirable preliminary to its use, as otherwise it must be crushed and ground, which will be found very destructive to millstones; but even when this is done, it is desirable to use, instead of the slag alone with limestone, an admixture of a pure clay high in combined water. This water, escaping at a high temperature, seems to act on the sulphur in the sulphide of calcium in the slag and remove considerable of it as sulphuretted hydrogen. The threefold mixture combines other advantages with the foregoing, the fusibility of the slag at the temperature of the kiln making the combination of clay and lime more certain and regular and less dependent upon the perfection of the mechanical combination.

In many cases, clays and shales contain iron pyrites, or sulphide of iron. Where this is the case, they should be avoided, unless, as in the case of the black shale above mentioned, they can be given a preliminary burning. This shale can be easily thus burned, as it contains a

large amount of organic matter, and could be stacked up with a little coke slack and burned in piles.

The above described materials are those which, in this state, are most available for cement manufacture. They do not, however, cover even a considerable proportion of the list of things from which it can be made. Marls, trap rocks, slates, "alkali waste," and many other lime and silica compounds could be thus utilized. Some clays and marls, having a large proportion of lime in them, would be particularly well adapted to the purpose, and most excellent results have been obtained from such materials in Denver, Colorado, where Portland cement is made from a marl and limestone, having the following composition:

	Limestone.	Marl.
Carbonate of lime	95.0	63 5
Insoluble silicious matter	5.0	32.6
Alkali and magnesia	undet.	4.5

The first step in the investigation of the available material for cement making at any point should be a careful chemical analysis of such limestones and clays as can be obtained cheaply and in abundance, not neglecting any of the other substances mentioned, should they occur in quantity. The analyses should be made on large and carefully averaged samples, or the results may be entirely misleading. The freedom of the clay from grit or sand should be ascertained, and if the limestone is not low in silicious matter, this should be in the form of clay and not of sandy particles. The next thing to ascertain is the proportion and result of burning of the materials. This will require a course of experiments which must be thoroughly carried out. The apparatus necessary is a large mortar and pestle, a pair of scales, and some substitute for a kiln. This may be a small "try kiln" like those used at most cement works for testing stone, and which are always used where Portland cement is manufactured, to control and test the mixtures, or perhaps just as well, an ordinary stove with a good draft, capable of holding coke enough to burn two or three hours. The fuel required, coke, should be free as possible from sulphur. If this element is present in quantity, the cement made in these preliminary tests will have a most discouraging blue color when set, and be of but inferior value, even if the material be all right.

The proportions of mixture can then be calculated from the analysis. The following analyses of various brands of Portland cement will serve as a standard:

	1	2	3	4	5
Silica	22.23	22.74	20.96	24.06	24.10
Alumina	7.75	7.74	9.48	5.93	7.51
Oxide of iron	5.30	3.70			
Lime	54.11	56.68	60.25	62.61	60.79
Magnesia	undet.	0.57	2.97	0.66	3.52
Alkalies	2.66	0.63	undet.	1.15	0.89
Water and carbonic acid	undet.	5.40	undet.	undet.	undet.
	92.05	97.46	93.66	94.41	96.81

1. German Cement (Serlo).
2. Best English Portland (Reid).
3. Giant Portland (American).
4. German Imperial.
5. American Portland, made in Ohio of slag, clay and Columbus limestone.

There is considerable variety of composition. What the law is which exactly governs the proportions to give the best results, it is difficult to say; but from numerous tests made by the writer on cement materials, the conclusion reached practically is that for each kind of material there is a best composition for the resultant cement. So that the method of procedure would be to take some one element as a basis and vary this until the desired result was obtained. This is best done by taking the ratio of silica to lime. Taking various analyses given above, if the lime be divided by the silica in each case, the result lies between 2.5 and 2.9. Given, then, a limestone and a clay, if the percentage of silica in the limestone be called A, and in the clay, A′, and the percentage of lime in the limestone be called B, and in the clay B′, then if x is the amount of clay to be added to 100 parts of limestone,

$$\frac{100.B+x.B'}{100.A+x.A'}=2.5 \text{ to } 2.9 \text{ or } x=100\left(\frac{B-(2.5 \text{ to } 2.9)A}{(2.5 \text{ to } 2.9)A'-B'}\right).$$

With the given materials, a series of mixtures ranging from the 2.5 to 2.9 limit should be made. The materials being carefully weighed out, they may be put in the mortar, not separately but together, and then pounded and rubbed to an impalpable powder. This powder is then to be moistened with water to a stiff paste, made into balls the size of the fist, and let thoroughly dry over a warm stove. When dry, they may be burned in the kiln or stove, as follows: A clear and bright coke fire, eight or nine inches deep, is covered with a couple of inches of new coke.

The balls are laid into this and then covered with a few inches of new coke, then the whole let burn through to ashes. If the draft is good, the balls will be gradually heated to a white heat, and then will gradually cool off. Before the fire goes out, one of the balls should be withdrawn and cooled. This may, as soon as it gets cool, begin to fall to powder, and in a few minutes nothing be left but a heap of dust. In this case, the clinker is said to be "slacking" or "dusting," and the balls left in the stove may share the same fate. If the heat has been insufficient, the balls will come out light-colored and speckled with a chalky look on the fractures. If the heat has been excessive, the balls may melt to a glassy slag, and in this state will show no cement properties. If the heat was right and the mixture correct, the balls should be found in the ashes, shrunken, but not very much "dusted," and when broken, should show on the fracture a rough, dark, greenish-black, scoriaceous surface, not glassy, but when examined in the sunlight, exhibiting glittering points. Some of the balls with the different proportions will show this result. Such should be then finely pulverized in the mortar. The powder can then be tried by mixing a little with water and seeing how it sets. Part of it should be kept for a few days, spread out on a board to "age" and then tried again. Freshly burned cement is frequently contaminated with a little free lime, which causes it to crack and disintegrate when set, but by keeping it exposed to air for a few days, or even weeks, when in large amount, this is removed and the strength of the cement appears. In one experiment of this kind by the writer, a sample lot of cement was burned, and the clinker, owing to slight overliming, would hardly set at all, but after keeping some time, it set in the mould and stood 250 pounds tensile strain on one square inch section seven days old.

Such a set of experiments repeated for a few times will serve to show whether the material will make cement and what the proper ratio of silica to lime will be for those compounds. The main points to take care about are the sufficiently intimate mixture of the ingredients before burning. If none of the proportions give a "clinker" that will stand cooling and will set, there is probability of a deficiency in alkalies; and a new set may be tried, adding to each batch about one per cent. of soda or potash, The effect of this small addition in developing cement properties is sometimes remarkable.

The proper ratio of silica and lime being ascertained, it must be adhered to in all subsequent working of the material; and if, as is usually the case, the rock varies slightly, it must be controlled by analysis, and the percentage of mixture altered to suit the variation in lime and silica. The clay will not be likely to vary much, as a bed of good

clay runs about the same throughout. Where furnace slag is a part of the mixture, it must, of course, be constantly watched by analysis to keep the "mix" right, though if taken from a furnace while it is running on the same stock, there is surprisingly little variation, as the following determinations of silica and lime in a furnace slag used in cement manufacture show. The analyses were made some months apart, but of slag from the same furnace.:

	1	2	3
Silica	34.0	34.8	34.4
Lime	49.1	48.5	47.7

The manufacture of Portland cement on a large scale is only the carrying out of the conditions of the above described experiments, but the mechanical difficulties to be overcome are considerable, and the two points most essential to the success are, first, sufficiently fine grinding of the materials, and secondly, thoroughly intimate admixture. Either of these steps being faulty, the process will fail. The method adapted to the materials in this country is that described by Reid and others as the "dry process," as distinguished from that in which clay and chalk are mixed in a semi-fluid mass and allowed to settle and dry together, as done in the English works. The process is so called because the material is ground dry by millstones or other machinery for pulverization. It can, therefore, be used for any hard material. Two methods of proceeding are possible, either to grind the materials separately and then mix them in the proper proportions, as is done at some works, or else to mix the unground material, once for all, in the amounts required, and then to grind the whole together. This latter procedure has the advantage of affording the closest possible union of parts, and is to be recommended where the nature of the materials permits its adoption. The following description of a mill using the "dry process" and making a Portland cement from limestone and clay will give the method of proceeding. The stone was the ferriferous limestone, a crystalline and tolerably hard rock, the clay, an ordinary "bog clay," soft and free from grit. When brought to the mill, this was spread out on a small dry floor of tile heated by flues passing underneath, and there dried until in condition to be ground. Thence, it was taken to a small clay-mill of iron, ground to powder, and the dry powder lifted to bins in the upper part of the mill building. The limestone needs no drying, but is

charged directly into a crusher, which, in this mill, was of the "Foster" pattern. The stone is crushed as fine as small gravel, then elevated to a bin above the buhrs, of which four are devoted to grinding the limestone. It is delivered from the millstones as a very fine powder and lifted by elevators to bins above, as in the case of the clay. These bins are above the "mixing floor," where the ground clay and stone are run into a changing barrow, such amount of each as is necessary, the mixture being made by weight, platform scales with set weights (furnace scales) being used. This barrow load of weighed material is then dumped into a large revolving pan mixer, water added as necessary, the whole being mixed by the stirring arms of the machine for twenty to thirty minutes. It is essential that the operation be most thorough. The mixture, now in the form of a moderately stiff dough, is dropped into a small "clay blocker," such as is used in tile or brick-making, and forced out as a cylindrical mass, which is cut up and loaded into iron trucks, which run with it into a drying oven, this latter being an arched gallery heated by a small grate and about sixty feet long. The "mix," after drying thoroughly, is ready for burning. This operation is performed in cylindrical kilns thirty-six feet high and about eight feet in diameter. The method of charging and burning is to put first a quantity of wood in the bottom of the kiln, which is closed by temporary grate bars of iron leaving a space below. On the wood, coke is placed, and above it the dried blocks of material mixed with coke, the amount of coke being regulated by the heat required to burn the charge, which varies with different proportions of mixture. The kiln is filled up to the top, after setting fire to the wood at the bottom, which in turn ignites the coke. The burning is watched with great care. It must be slow, and yet the final temperature must be very high to bring the mass to incipient vitrification. As the mass sinks, more coke and material is added to the top, until the kiln is filled, when it is covered over with coke and allowed to burn out and cool. When cooled a little, the charge is drawn from the bottom and picked over, and over or under-burned "clinker" separated, and the rest taken to the mill for grinding. Many accidents may occur in the kiln. If the mixture was not dry enough, it may "dust," or fall to powder, and choke the draft so as to leave a large portion of the kiln "raw"; or if the proportion of the ingredients was not right or the mixing imperfect, the clinker, after burning, may fall to dust and choke the kiln; but if all was correct, the "clinker," when drawn, should be mostly in lumps with a dark greenish, submetallic look and rough granular structure. A certain tendency to fall to powder, if drawn too hot, is not objectionable, provided it is not

excessive. The cement is now sent through another crusher, and the crushed cement run through millstones, of which there are six "run" or pairs. An ingenious arrangement for removing the particles of iron which form in the kiln from the limestone, as this contains a little iron ore, consists of a powerful magnet, over the surface of which the material drops into the millstones. To this the iron adheres, and is cleaned off, thrown to one side by a little scraper acting periodically. The ground cement is lifted by elevators to bins for storage. The amount of cement obtained depends somewhat upon circumstances, but with clay and limestone, will average about sixty per cent. of the raw material.

In a more recent works, making cement from slag, stone and clay, the process is simplified by mixing the raw material in the requisite amounts. This mixture is then run through a crusher and to the buhrstones directly. From there, after a short mixing in a pan with sufficient water to make it into a dough, it falls on to a tile dry floor, where it is spread out, and when partially dry, cut up by a spade into roughly square blocks, which, when dry, are taken to the kiln. This avoids the use of the blocker and elaborate drying ovens. The blocker cannot be used where slag enters the mixture, as this, when fine, acts as sand and chokes the machine, owing to its not being plastic. Hence, no sort of pug-mill can be used with slag. This point, the writer has established by careful trial. The common method of burning in discontinuous kilns is wasteful of fuel and irregular in action; and some large works are using various forms of gas kilns, moulding the mixture into regular bricks by machinery and burning them as fire-brick are burned, only at a higher temperature. Such is, briefly, the method by which the most various materials may be converted into a Portland cement. The resultant cement will be in all cases practically the same, if the process is carefully conducted.

The cement, as it comes from the buhrs or millstones, is rarely fit for immediate use, differing widely in this respect from the natural cement. The material must be allowed to air-slack, or, as it is technically termed, "cool." This process demands a more or less lengthy exposure to the air, with occasional turning over. The cement changes perceptibly in character, becoming finer and softer. The change is, partly at least, due to the air-slacking of the small amount of free lime almost unavoidably present in the burned clinker; but there are other changes less simple in character which also take place, by which the strength of the cement is greatly increased, so that even a cement that apparently sets-up strong and sound when fresh, will show a much increased strength if kept a few weeks. Many kilns full of cement will, if mixed with water when quite fresh, crack and disintegrate more or less, or "blow"

as it is termed, but will lose this very dangerous quality entirely if kept sufficiently. Pressure of orders will sometimes cause cement to be sent out from a mill too early, and in such cases much damage to the reputation of a brand may be done. Cement sometimes swells during the process of slacking, and if barreled too soon may burst the packages. This process of "cooling" requires exposure to air, and takes place only very slowly; if the cement is kept in large bins three or four feet deep, it must be worked over, and should lie not over two feet deep.

While the materials for making cement are very abundantly distributed, it is very possible to make bad cement from the best materials; and hence, constant care and watchfulness are requisite to prevent this accident. Some of the principal ways in which failure may occur are the following:

Errors in proportion of mixture. An "over-limed" cement, in which the per cent. of carbonate of lime was too high in the original mixture, is usually very heavy and hard. It sets slowly, and shortly after setting begins to crack and blow, like a cement too fresh for use; but ageing will not remedy it, in case the mixture was badly over-limed. An over-clayed cement, in which the alumina and silica are in excess, will set quickly, but will never gain much strength, and is liable in time to crumble and disintegrate.

The errors in proportion, however, are more easily avoided than those of manipulation. A cement in which there is insufficient fineness in the materials may have the evils of both an over-clayed and over-limed article. It will be light, set quick, have no strength, and crack to pieces subsequently. The same faults may appear if the cement is under-burned. Over-burning results usually in a very slow-setting, heavy cement, which may have little strength, and will be long in slacking sufficiently to be safe to use.

If the proportions, mixing, and burning were right, the cement, after a reasonable time for air-slacking, should, when mixed to a stiff dough with water, "set" in from a half-hour to two hours, so that it can be placed under water; and when so submerged, it should gradually gain hardness, showing no tendency to crack, swell, or shrink.

The fineness to which cement is ground is of the utmost consequence. The fact is clearly established by Faija and others, that only the most impalpable powder has any value as cement; that if a given cement be sifted through a sieve of 5,000 holes to the inch, the part not going through the sieve will, when mixed with water, have absolutely no cement power, though the finer part may be of the highest grade, and the coarse part will itself yield the best possible cement if re-ground to a dust. Hence, the coarser parts are simply like so much sand, and dilute

the cement accordingly. It is for this reason that millstones are so difficult to replace by other and less expensive grinding machinery. They produce the maximum of dust for a given degree of pulverization, and it is the dust that is wanted. The finer the cement is ground, the greater the amount of sand it will carry, and as this determines the cost of mortar or concrete, a fine cement is worth more than a coarse one in money.

Injurious impurities in Portland cement may destroy its value. The principal ones are sulphur and magnesia. The action of sulphur is to cause in time a disintegration of the cement, and it should never be present in cements in more than fractions of a per-cent. It may be derived from poor material carrying pyrites, or from the fuel used in burning. A coke high in sulphur will, in this way, ruin cement. The use of clay will tend, to some extent, to keeping this impurity low, as before mentioned; but where no or but little clay enters the mixture, the coke must be most carefully looked to. Cement containing an undue amount of sulphur will sometimes turn blue on setting under water for some time. This color will be seen in the interior of the mass on breaking, while the surface may be the normal color.

Testing Cements.

The great variety of purposes to which cement is applied, together with the number of kinds of cement used, makes it important that an intelligent system of selecting and testing be employed.

It has been seen that there are two groups of cements which are in use, those that are quick-setting, comprising the lighter-burned natural cements, like Louisville or Rosendale, and the heavy artificial Portland cements, slow-setting and very strong when properly made. The use of each kind is distinct, and in its own particular field cannot usually be replaced by the other. It is also apparent that each kind is liable to be faulty at times, either from bad materials or careless manufacture. Now, users of cement must, if they wish to be secured against errors and fraud, test in some way the value of the material they use.

Two kinds of tests are needed, and these two are distinct. First, the determination of whether a given brand or grade is suitable. The testing of a new cement is a slow process and must extend over a long time. No ordinary short series of tests will answer definitely the question, "Is it a good cement?" as its permanent value will only appear after having the test of time and exposure; but where a cement of a given brand, having a good reputation is used, it is reasonable to infer that if it is of the average quality made by that works, or from the same material, it will be as safe and permanent as the brand is known to be.

It is to this point that most of the systems of testing cement are directed. The subject of testing cement was investigated by a special committee of the American Society of Civil Engineers, and the results of their experiments embodied in a report on a uniform method of cement testing (Transactions American Society of Civil Engineers, November, 1885).

The tests recommended are for fineness, soundness, or freedom from tendency to check or disintegrate, and tensile strength of the set cement. As before stated, the fineness is the measure of the ability to carry sand. This is determined by sifting a weighed amount of the cement through a sieve of standard mesh. The committee recommend three sieves of 2,500, 5,476 and 10,000 meshes to the square-inch. Fairly ground cement should not leave more than five to ten per cent. on a 2,500 mesh sieve.

The test for soundness is to make a pat or cake of the cement with water, about three inches in diameter and half an inch thick, spread out on a plate of glass until set, and then put in water and examined from time to time. A similar cake of cement should be set in air. Neither must develop cracks or "checks." A fresh sample of cement may crack under this test, as has been seen, and yet be restored to soundness by age. This checking test, in the case of known brands, is valuable to ascertain whether the cement is too new for use.

The test for tensile strength requires more machinery for its application, but many efficient forms of cement testers are on the market. There is great difficulty for obtaining uniform tests for cement, and the tests of different persons will vary greatly. Hence, any one who tests cement should begin with a number of known and approved kinds, so as to establish his own standards of comparison. The cement is tested either "neat" or with sand. The sand test is recommended by the Society of Engineers in addition to the "neat" test, but Henry Faija, in his book on "Cement Testing," calls attention to its extreme uncertainty, as variations in sand correspond to greater differences than variations in cements. The committee, however, propose a standard sand to obviate this difficulty.

The briquettes, or little blocks for testing, are made of a prescribed shape, and have a section of one square-inch at the breaking point. The cement, being mixed rapidly and thoroughly with just sufficient water to make a stiff dough, is pressed into the mould and allowed to set. When hard enough to remove, it is covered with a damp cloth, and after twenty-four hours, set in water for six days, then broken in a machine which registers the force required to effect rupture.

American and foreign Portland cements of fair quality, tested thus, will give from 250 to 500 pounds per square-inch, seven days old.

Natural cements will show much less—60 to 100 lbs. per square inch, as before stated, being their average strength.

The testing of an unknown brand would require a much longer time. Tensile strength tests after twenty-eight days, or even longer, must be made, as there are faulty cements which quickly attain a high strength, then gain no more, or even fall off in strength, or disintegrate in time. Faija states that a cement should gain an increase of twenty-five per cent. in strength at the end of twenty-eight days over what it has at seven days. Not only this test should be applied, but samples of the set cement should, after seven days, be set out in the air. Some cements will, under these circumstances, fall to powder gradually, and become worthless. Of course, this comes from faulty manufacture, probably, in the case of artificial cements, from over-claying the required mixture.

The details for testing the tensile strength of cement are fully elaborated in the report referred to. The common test for cement, by which a mason estimates its quality, are of little value. Mixing it with a "mortar" and putting it on a brick serves to compare the cement with the ordinary kind he uses as to speed of setting, color, etc., but gives no safe guide to an opinion of its real strength. In fact, many light and over-clayed cements yield a more easily worked mortar than the true Portlands.

The weight and color of cement is a popular means of testing it, but the indications are very fallacious. The weight of an artificial cement is due, first, to the extent and hardness of the burning, and second, to the fineness of the grinding, the finer, the lighter, and the lighter burned, the lighter. The color of Portland cement depends partly on the nature and partly on the proportions of the materials. Over-clayed cements are usually reddish or "foxy," and such hues may therefore indicate weakness. The proper color is from a light to a dark-gray, with a rather greenish cast.

In this short sketch of the nature, sources, and preparation of cements, it may be well to again call attention to the many advantages Ohio possesses as a place of manufacture of the artificial cements. We have numerous limestones which cannot be exceeded in purity as sources of carbonate of lime. With these are the drift and bedded clays of every variety, and furnace slags, slates and marls of all grades. There are many points in the state where cements of excellent grade could be cheaply and easily manufactured. A small works at Columbus is at present trying the experiment of working clay, limestone and slag. While connected with these works as chemist, it became the writer's duty to experiment on the different materials available; and

while, from commercial reasons, the supply of material is now exclusively Columbus limestone and the plastic clays near Logan, in Hocking county, during the investigation excellent Portland cement was made from the drift clays of various points, with and without slag admixture. There are better limestones to be had in the state than the Corniferous used in Columbus, which has a considerable amount of gritty silica. At South Bend, Indiana, a fine Portland is now made from a drift clay and a bed of shell marl. The two are so soft as to be easily incorporated, almost without grinding, and burned to a most excellent "clinker." The cement is largely used in paving, and other work requiring good Portland.

CHAPTER XIV.

GYPSUM OR LAND-PLASTER IN OHIO.

By Edward Orton.

Distribution.

Land-plaster or gypsum (sulphate of lime) is at present worked in Ohio at but a single locality, viz., the station of Gypsum, Ottawa county, on the Lake Shore and Michigan Southern Railway, ten miles west of Sandusky, and by only a single firm, viz., Marsh and Company, of Sandusky. The mineral has been known here since the first occupation of the country, coming to view in the rocky floor of Sandusky Bay, immediately adjacent to which the quarries are located. Not more than twenty-five acres have been already worked out, and there is probably as much more territory that has been proved to contain gypsum in quantity to justify working, while a larger acreage to which no thorough tests have yet been applied may be reasonably expected to hold valuable deposits. Most of the proved territory is included in the two hundred acres that Marsh and Company own, but in past years quite a large amount has been taken from the farm adjoining this, upon the west. The surface, which is composed of the usual Drift clays, is but a few feet higher than the waters of the bay. In the quarries that have been thus far worked, the drift has been very shallow, being confined mainly to troughs or hollows in the limestone, the results of earlier erosion.

Geological Horizon.

The gypsum of the locality above described is derived from the great series of limestones which is known in the Ohio scale as the Lower Helderberg or Waterlime formation. This series is much the largest single division of limestones in the state. Its maximum thickness under cover does not fall short of 700 feet. In outcrop, we do not find more than 100 feet in vertical sections which can be connected in a combined section. The largest measurements of this sort are found in

Highland county, near Greenfield. In the northern part of the state, there are frequently found, rising from under the drift beds that cover and obscure all of the bedded rocks, sections of a few feet of the Waterlime series, but it has not been possible hitherto to combine these isolated sections in any way so as to show the entire thickness of strata represented by them. The breadth of country occupied by the formation, however, is good enough proof that it has a thickness as great at least as that claimed for it above.

Gypsum appears to be distributed at frequent intervals throughout this series in this particular portion of the state. In the deep well drilled in 1886 at Sandusky, a bed nine feet in thickness was reported by the driller at a depth of 272 feet, or about 150 feet below the base of the Corniferous limestone. It was also reported in smaller amount at many other points in the next 800 feet of rock passed by the drill. It is, however, possible that the gypsum which actually occurs in the drillings from a considerable number of points in the descent may have been, in part, at least, derived from the highest deposits by the action of the rope and the passage of the tools in drilling.

At Port Clinton, also, three miles to the westward, gypsum was found at various points from 90 to 190 feet below the surface. These deposits are deeply buried at the quarries now under discussion and must be correlated with some of the lower beds at Sandusky, already reported..

The former reference of the gypsum of the quarries to the Salina group must be abandoned. Twenty-five miles west of this locality, viz., at Genoa, the Waterlime is found resting directly upon the Guelph beds of the Niagara. It carries here its most characteristic fossil, viz., *Leperditia alta*. It is 400 feet or more *above* this horizon that the gypsum beds are found.

The assignment of these gypsum beds to the Lower Helderberg series is rendered much less revolutionary than it would have been thought to be a few years since, by the discovery that some of the important plaster quarries of central New York are to be referred to this same series. This discovery was made by Professor S. G. Williams, and is recorded by him in the American Journal of Science, September, 1885.

At various other points, gypsum is found in the outcrops of the formation, and notably in the vicinity of Sylvania, Lucas county, while in the deep wells recently drilled through northern and central Ohio, it is the exception to miss deposits of gypsum in the samples of drillings. The last case reported is three feet of pure fibrous gypsum from a depth of 150 feet at Upper Sandusky.

Mode of Occurrence and Origin.

The plaster beds occur in the following sections, viz.:

Drift clays		12–14 feet.
	(Level of bay, eight feet below surface.)	
No. 1.	Gray rock, carrying land plaster	5 feet.
	Blue shale	½ foot.
No. 2.	Bowlder bed carrying gypsum in separate masses imbeded in shaly limestones	5 feet.
	Blue limestone, in thin and even courses	1 foot.
No. 3.	Main plaster bed	7 feet.
	Gray limestone, in thin courses	1 foot.
No. 4.	Lowest plaster bed, variable	3–5 feet.
	Mixed limestone and plaster, bottom of quarry. Water enters here in quantity.	

The beds are not even and horizontal, but are found in waves or rolls, the summits of which rise five to eight feet above the general level.

Sections like the one here given will yield 50,000 tons of plaster to the acre.

The bed marked No. 1 in the section, is a mixed deposit of shale and plaster that has hitherto been rejected, but which has recently been found fully available for grinding into a dark-colored land-plaster. It has been lost by erosion in much of the territory already worked, and is not commonly counted among the valuable resources of the quarries.

No. 2 is one of the most interesting divisions of the section. Scattered through the calcareous shales, balls of gypsum, concretionary in form and probable character, varying in diameter from six to twenty-four inches occur. For a long while it was thought that they were of inferior value, and they were ground into land-plaster, but recently it has been found that the purest product of the quarries can be derived from these same plaster balls. The gypsum yielded by them when they have been carefully freed from their shaly envelopes, proves to be of the whitest and purest sort such as is used as *terra alba.*

But the division marked No. 4 is the main reliance of the quarries. It is from this that the chief supply of plaster for calcination is derived. The gray rock by which it is separated from the overlying section, is an even-bedded limestone of the most characteristic Lower Helderberg type. It contains a considerable percentage of gypsum distributed through the rock, as is shown in the following analysis: (*Lord.*)

Carbonate of lime	34.20
Carbonate of magnesia	28.49
Sulphate of lime	27.76
Alumina and oxide of iron	1.21
Silica	0.31
Water, not determined	
Total	91.97

A rock of this character will make an excellent fertilizer for many soils, but it would not be profitable to grind it here where the better grades are equally available.

The composition (in part) of the blue limestone that is found between divisions two and three (No. 1), and of the shaly envelope by which the plaster bowlders are covered (No. 2) are also given herewith. They are constituted as follows: (*Lord.*)

	1	2
Carbonate of lime	43.48	28.55
Carbonate of magnesia	36.07	24.40
Silica	16.45	41.93

A careful search was made for fossils in the limestones that include the plaster beds, but none were found. The conditions would necessarily be unfavorable to all forms of life, where beds of gypsum were in process of formation.

As to the origin of these accumulations through northern Ohio, all the facts point to deposit from a shallow, land-locked and contracting sea during the Lower Helderberg period. The first deposit from such a sea, undergoing concentration, is sulphate of lime, either in the form of gypsum or anhydrite. The latter form is very often found in connection with beds of rock salt, immediately underlying them as a general rule. At only one point in northern Ohio, have beds of rock salt been reported in this series, viz., at Newburg, near Cleveland. The facts pertaining to the salt discoveries there are given on page 352.

The shallowness of the sea in this period is well established by the sun-cracks and wave-marks that are so conspicuously shown in the rocks that represent it throughout their outcrops in this part of the state. That the sea must have been land-locked or cut off from free communication with the main ocean is also an obvious deduction from the concentration of the sea-water that went forward.

The facts pertaining to the gypsum deposits now under consideration were given by Newberry, Geol. of Ohio, Vol. II, page 135, and valid conclusions were drawn by him as to the mode of origin of these deposits. He urged the views presented on the previous page, and showed the unsatisfactory nature of the alternative explanation, viz., that beds of gypsum are due to the action of the waters of acid springs on beds of carbonate of lime. The wide-spread discoveries of deposits similar to those of Ottawa county in the deep wells that have been drilled in

such numbers throughout northern Ohio during the last three years, reinforce and sustain this view in a very effective way. The acid-spring theory, no one would be bold enough to urge as an explanation of deposits that are measurably continuous over thousands of square miles of territory.

Composition and Uses.

The gypsum produced by the quarries now under consideration is devoted to two main uses, viz., calcined plaster or stucco, and land-plaster. About forty per cent. goes to the first product, and sixty per cent. to the latter. The total value of the calcined plaster considerably exceeds, however, that of the land-plaster. Under this latter division, the dental plaster, the glass-works plaster, and also the *terra alba* of the works is counted.

The calcined plaster of Marsh & Co.'s production is recognized in the markets as of great excellence and purity. Its reputation is fully sustained by the following analysis, made from an average sample of the output of the quarry: (*Lord.*)

Lime	32.52
Sulphuric acid	45.56
Water	20.14
Magnesia	0.56
Alumina	0.16
Insoluble residue	0 68
Total	99.62

The best stone of the quarry goes into this division. All that is streaked with shale or from any cause "off color," is turned into land-plaster. Into this division is also put all the surface stone which is known as "rotten plaster." The latter is somewhat stained by surface infiltration, but chemical analysis shows that it has lost nothing of value. The figures are as follows: (*Lord.*)

Lime	32.76
Sulphuric acid	46.20
Water	20.00
Magnesia	0.03
Alumina	0.29
Insoluble residue	0.46
Total	99.74

Evidently the sample tested belongs to the best product of the quarry.

The analysis of the land-plaster in like manner shows the great excellence of the entire product of the quarries, and the slight differ-

ences that separate the two divisions which are made of it. It is as follows: (*Lord.*)

Lime	32.35
Sulphuric acid	46 38
Water	19.70
Magnesia	0.54
Alumina	0.60
Insoluble residue	0.91
Total	100.48

A small amount of the purest stone, and mainly derived from the bowlders previously described, is supposed by the manufacturers to be used as *terra alba*. The main applications of this form of gypsum are in mischievous adulterations. The calcined plaster reaches the general markets of the country as far east as Pittsburgh and Buffalo, and to the southward indefinitely. The land-plaster is largely used in Michigan. Ohio farmers have been slow to avail themselves of this excellent fertilizer. About 6,000 tons are used annually by glass manufacturers. The production of these quarries is specially adapted to this demand.

Production.

The production of the quarries and works for the last few years are shown in the following table:

	Calcined plaster.			Land-plaster.		
	Barrels.	Average price.	Total value.	Short tons.	Average price.	Total value.
1881	12,409	$1 55	$19,234	3,705	$4 35	$16,117
1882	16,888	1 46	24,656	4,404	4 33	19,069
1883	20,919	1 41	29,496	4,678	4 15	19,414
1884	20,307	1 38	28,024	4,217	4 09	17,248
1885	8,686	1 31	11,379	4,038	4 03	16,273
1886	21,256	1 29	27,420	4,186	3 87	16,200
1887	21,981	1 28	28,135	4,098	3 87	15,860

The works are now in excellent condition, having been rebuilt in 1885. (This fact accounts for the small production of that year). The mills were previously located at the railroad, nearly a mile distant from the quarries, and large expense was incurred in hauling the stone

to the mills, but now a railroad switch runs in to the quarries and excellent facilities for hauling the stock and loading the product have been secured.

The works will allow an easy expansion to meet an enlarging demand. There is enough proved gypsum to keep the mill in operation for a considerable term of years, and there is good reason to believe that when proper exploration shall be undertaken, large accessions will be made to the acreage already known.

An attempt was made by Marsh & Co., in 1885, to introduce the roller process for grinding the rock, but the experiment proved unsuccessful, and a return was made to the time-honored method.

The water that fills the quarries to the lake-level, unless kept down by the pump, is a strong sulphur water, carrying a notable quantity of sulphuretted hydrogen. The source of this product is probably to be found in decompositions of the gypsum of the rocks through organic matter carried downwards by surface waters. Such an origin is possible, at least. The oxidation of the sulphuretted hydrogen gives rise to sulphuric acid which produces an acid re-action in the water, rendering it unfit for boiler use.

CHAPTER XV.

THE PRODUCTION OF LIME IN OHIO.

By Edward Orton.

The production of lime is an important and growing interest in Ohio. Lime is burned in the large way, and generally for railroad or lake shipment, from stone quarried on the spot, in the following counties of the state. The enumeration is begun in the southwestern quarter:

Highland,	Shelby,	Wood,
Clinton,	Franklin,	Lucas,
Greene,	Delaware,	Van Wert,
Montgomery,	Marion,	Sandusky,
Preble,	Hancock,	Ottawa,
Miami,	Seneca,	Erie.
Clarke,	Wyandot,	

To this list Cuyahoga county may be added, as a large amount of lime is burned here from stone brought in by the lake from Marblehead and Kelley's Island.

In twenty or more other counties, lime is burned for local use or even for occasional shipment, but there are no important centers of production within them at the present time. In several of the counties in this last group, the conditions for a large production are found, so far as limestone of desirable quality is concerned, but they do not command equal advantages with the counties of the first list in the matter of transportation and markets.

All of the large production comes from the western half of the state. In forty-two out of fifty counties that make up western Ohio there are limestone quarries available from which lime of greater or less excellence can be produced.

I. Geological Horizons.

To name the several geological formations from which lime is or can be burned in Ohio, requires the enumeration of almost all the ele-

ments of our scale. A brief review of the possible sources of our supply will find place here, beginning with the lowest and oldest:

The Hudson River Group.

This is, practically, the lowest formation that comes to the surface in the state. There is a single small outcrop of the Trenton limestone at Point Pleasant, and the horizon of the Utica shale is uncovered at a number of localities in the deepest valleys of southwestern Ohio, but if this formation is not entirely lost here by overlap, it has at least been so changed from its typical character and so closely assimilated to the Hudson River series that it is scarcely worth while to attempt to disentangle it from the latter.

The Hudson River group consists of alternating layers of limestone and shale, the relative proportions of which substances vary greatly in different parts of the series. The beds of limestone are available for the manufacture of lime, but the quality of the product is not satisfactory for any but the coarsest uses, as in foundations and road masonry. The limestone when free from the shale contains about ninety per cent. of carbonate of lime. The percentage of magnesia is small, but alumina and oxide of iron occur in proportions large enough to make a dark lime. This last fact is a chief objection to the lime of this formation. Its cementing power is good, and the clay that goes with the stone when burned fresh from the quarries doubtless confers on the calcined product hydraulic quality in addition to that of common mortar, but the product is too dark to allow it to be used with approval in brick-work or in plastering. For the coarser uses, however, as already stated, this "blue limestone" lime is much valued. It is claimed that it makes a more solid and durable foundation, especially in damp locations, than much of the white lime. The claim is very likely a just one.

The composition of the stone in its best phases is seen in the accompanying analysis: (*Wormley.*)

Carbonate of lime	91.50
Carbonate of magnesia	5.06

These figures, however, represent but little of the limestone of the series. The impurities generally constitute not less than eight to ten per cent. of the rock.

Lime production from this series of limestones is not at present of any large importance, and it does not appear likely to become more so. The stone is harder to burn than those that yield the white limes, and the cost is on this account increased, while at the same time the quality is much less desirable.

The Clinton Limestone.

The Clinton limestone is not the source of a large production, but there are a few counties in which it is now manufactured into a lime of great excellence. Its general composition is indicated in the following figures: (*Wormley.*)

Carbonate of lime	84.40
Carbonate of magnesia	12 98
Alumina and oxide of iron	0.90
Silicious matter	1.50
Total	99.78

At a few points in its outcrops, however, it leaves these proportions far behind and becomes the purest limestone that occurs in Ohio. In fact, no purer carbonate of lime is found anywhere, in the large way, than that which the best phases of this formation supply.

The Niagara Limestone.

In this complex series, there are several subordinate horizons of lime.

The Dayton stone, the place of which is at the very bottom of the Niagara shale, is a limestone of substantially the same composition as that last reported, averaging about eighty-five to ninety per cent. of carbonate of lime, and five to ten per cent. of carbonate of magnesia. It was burned for lime on quite a large scale in the early days of the country, but no account whatever is taken of it for this purpose at the present time.

The series of even beds that occur directly above the Niagara shale and that make the chief reliance of the formation for building-stone, are impure magnesian limestones, selected portions of which yield an excellent hydraulic lime. They are never used in lime production.

The upper division of the Niagara group, which is known as the Guelph or the Cedarville division, is one of the three great sources of lime in Ohio. This division, throughout its whole extent, which reaches a maximum thickness of 300 feet, is in most parts of the state a dolomite or magnesian limestone of great purity and excellence. The following figures indicate its composition throughout its outcrops in southern Ohio. They are derived from an analysis of the best phase of the Springfield limestone: (*Wormley.*)

Carbonate of lime	55.10
Carbonate of magnesia	43.05
Alumina and oxide of iron	1.70
Silicious matter	0.10
Total	99.95

The composition of the formation in northern Ohio is equally pure, as appears from the analyses of Lord, to be found on later pages of this chapter. A single one, that of a sample from Genoa, Ottawa county, is given here as fairly representative of a large number:

Carbonate of lime	55.59
Carbonate of magnesia	43.67
Alumina and oxide of iron	0.42
Silicious matter	0.28
Total	99.96

The Waterlime or Lower Helderberg,

In this formation, a large amount of stone is found that exactly agrees with the series last described. This phase occurs both in northern and southern Ohio. No analyses are needed to illustrate this statement. The figures that indicate the results of analysis are indistinguishable from those that are derived from analyses of the Guelph. The stone of this character becomes the second of the main sources of Ohio limes. When the formation is not more than 100 feet thick, the whole of it is likely to have the composition above indicated. The lower beds, in particular, are quite sure to agree with the Niagara beds upon which they rest.

A large part of the formation, however, differs very widely from the description given above. Through the northwestern quarter of the state, and particularly in Hardin, Allen, and parts of Hancock counties, the formation consists of a dark and hard phase of the rock that carries along with the dolomite that is its main constituent, a notable percentage of alumina, iron and silica.

The Upper Helderberg Limestone.

This important stratum, which is commonly known as the Corniferous limestone, is the third of the main sources of lime in Ohio. Lime is manufactured from it at Columbus, Marion, Sandusky, Marblehead and Kelley's Island. The stratum contains several subdivisions that differ from one another in chemical composition, growing progressively richer in lime as they ascend in the scale. The lower courses are magnesian limestones, not very different from the Lower Helderberg, on

which they rest. The central division of the formation is represented by the following figures. (*Lord.*) The composition of the lower beds of the Kelley's Island quarries is given herewith:

Carbonate of lime	77.22
Carbonate of magnesia	20 19
Alumina and oxide of iron	0.14
Silicious matter	1.65
Total	99.20

This general order is maintained throughout all the exposures of the limestone in the state.

The Sub-Carboniferous Limestone.

The formations already named furnish all of the large supplies of lime in Ohio, but local additions are made from various other horizons. The Ohio shale yields no lime whatever, nor does the Waverly series proper, but a small supply is obtained from the Sub-Carboniferous limestone, which lies at the summit of the Sub-Carboniferous rocks of the state. The lime obtained from this stratum is quite variable in composition, but it is never dolomitic in character. It ranges in composition from seventy-five to ninety-two per cent. of lime and carries comparatively little magnesia, but the silicious and other impurities are extremely variable, and often occur in large amount. The lime production from this horizon nowhere possesses anything more than local importance, and indeed it has but little even of this.

The Coal Measures.

In this great and varied series, as is well known, a considerable number of persistent but generally thin limestones are found. A few of these possess a fair degree of purity as limestones, but the most of them carry iron, alcomina and silica in such large amount as to utterly unfit them for lime production. They furnish natural cements instead, and have been used to a small extent for this purpose.

At various points, however, in the wide distribution of all of these several beds, a higher degree of purity than ordinary is found, and these phases are found adapted to furnace flux and lime production.

The limestones of the Mercer, the Ferriferous and the Freeport horizons, the Cambridge, Crinoidal and Pittsburgh limestones, and the numerous unsteady sheets of the uppermost portions of the series are all occasionally turned to account for one or both of the purposes named. The Ferriferous limestone proper is by far the most valuable of the

whole series. Throughout a number of counties in Southern Ohio its character is uniformly good, and it has been the main reliance for furnace flux of an important iron manufacture established here for a long term of years. It is, of course, equally available for lime production. It carries not less than ninety per cent. of carbonate of lime.

The limestones of the Coal Measures are all of the same general character, barring the impurities that they contain. The percentage of carbonate of magnesia in them rarely rises above fifteen per cent., and never reaches dolomitic proportions.

The Drift.

The important series of deposits that compose the drift beds of the state carry a large amount of limestone in the shape of bowlders and gravel. This is especially true in the western half of the state. Where streams have washed away heavy banks of bowlder clay, or where gravel deposits are worked on a large scale, accumulations of limestone blocks derived from all the series to the north of the regions where they are found, are frequently burned in a small way as sources of lime. The lime produced in this way is not likely to be homogeneous in character, on account of the varied horizons from which the bowlders are derived. It sometimes happens that the burning is done entirely beyond the outcrop of the limestone formations, the gravel having been swept in over the Ohio Shales, the Waverly Group, or the Lower Coal Measures.

II. Kinds of Lime.

In the review that has now been made of the several sources of lime in Ohio, it is seen that limestones of various composition are used in the production at the present time. It is further seen that by far the larger part of our limes is derived from dolomites or double carbonates of lime and magnesia, the approximate proportions of which substances are respectively fifty-four and forty-four per cent. The smaller section includes the limes that are made from stone containing sixty-five to ninety five per cent. of carbonate of lime and five to thirty per cent. of carbonate of magnesia. The higher the proportion of the former element, the more characteristic is the product. The qualities of the limes produced from these two main divisions are well marked, and in several particulars are sharply contrasted. In describing them, these divisions will be known as the *magnesian* or *dolomitic limes* and the *calcareous limes*. The latter designation is objectionable on the score of tautology, inasmuch as *calcareous* means *made of lime*, but no other single word is at hand that will indicate the composition of this section, and it seems desirable to avoid a compound term, if possible. Even if willing to

employ a compound name, what designation can be suggested that will be at once characteristic and appropriate? We cannot properly call the limes of this class *true limes*, for this would imply that all other limes are false. We cannot call them *pure limes*, because they do not come up to the claim embodied in such a term. They are quite as likely to be impure as the limes of the other main division. For want of a better term, therefore, the division in question will be named as indicated above.

It will be borne in mind that a wide range in composition is included in the calcareous division, the percentage of lime varying from sixty-five to ninety-five per cent. So wide a range in composition must necessarily be accompanied by a considerable range in the quality of the limes produced. In describing the character of the limes made from the formations of this group, however, only the highest grade will be considered, viz., that in which the carbonate of lime equals or exceeds eighty-five per cent. of the weight of the stone. The statements made in regard to this grade will require to be considerably modified before they can be applied to the limes from the other extremity of the division, As the carbonate of magnesia increases, the lime produced approaches in quality the lime of the other main division. This is the same as saying that two divisions are not enough to include all of the limes produced in the state.

The truth is that no adequate and thorough examination of limes, embracing both the scientific and practical facts pertaining to them, has yet been made, or if made, has not been put on record. The best treatises that have been published on the subject fail to consider, much less to account for, some of the most common and important facts of observation pertaining to Ohio limes.

It is greatly to be desired that a thorough study of the subject shall be undertaken. Such a study will embrace the chemical and physical characters of the rocks from which the lime is made, the modes of burning, the behavior of the lime in slacking and in use, its "strength," as measured by the sand that it can carry, and also by the hardness of the bond into which it sets, and also its durability, involving all of its behavior as it acquires age. Each of these topics needs to be studied from both a scientific and practical stand-point. As it is, we are unable to answer even the questions of fundamental importance in regard to our limes.

The two groups of limes already named, and partially distinguished, are in active competition in the state at the present time, and each claims for itself decided advantages over its competitor. Both cannot be right in their claims, but there has never yet been any authoritative decision of the questions at issue. What these questions are will pres-

ently appear. The characteristics of the two groups will be briefly presented. Many of the facts pertaining to them have been stated in previous publications of the Survey, and particularly in Vol. I, page 475, et seq.

a. The Calcareous Division.

The limes of this division, as above limited, are classed as *hot*, *strong*, *fat*, *rich*, *quick-slaking*, and also *quick-setting* limes. Their leading characteristics are indicated in these descriptive terms.

They are called *hot* because of the high temperature produced in the process of slaking. Heat enough to set fire to wood is easily evolved in the operation. The elevation of temperature is connected with the rapidity of the process. The mortar made from the lime *sets* or hardens rapidly.

The limes are called *fat* or *rich* because of the large amount of hydrate of lime or *putty-coat* which results from slaking. In this process they increase in volume 200 to 350 per cent. They are counted *strong* for the same reason, it being assumed that the amount of sand which they will carry is proportioned to and dependent on the amount of the factor previously named, viz., the putty-coat.

The claim that is made by the parties producing this lime, viz., that its value can be gauged as against any other with which it competes by the percentage of lime that it contains without any reference to the magnesia, is supported, at least by implication, in some of the most authoritative statements that we have upon the general subject. (See *Gillmore* on "Limes," &c., page 70; *Cook*, Geological Survey of New Jersey, 1868, page 397, &c.)

The claim, however supported, does not match to our experience, and must be pronounced unfounded in its reference to Ohio limes.

Wherever caustic energy is required in lime, as in paper manufacture, for example, a decided preference for the limes of this class is justified. Probably, also, these limes are more efficient in gas purification.

b. The Magnesian Division.

The limes of this group, as found in Ohio, have had but scant justice done them in the general treatises. All of them would be classed by Gillmore, for example, among the *poor* or *meagre* limes. He describes the limes of this class as slaking sluggishly, and seldom producing a homogeneous and impalpable powder. He says that they are to be employed as mortar only when it is impossible to procure other lime or cement. He is right in asserting for them a smaller increase of bulk in slaking

than belongs to the limes of the previous section. The rate of increase is believed to be about 200 per cent. ("Limes, &c.," page 70.)

Such statements as those first quoted are wide of the mark, so far as Ohio limes are concerned. The facts pertaining to this division were fairly stated in the passage already referred to in Volume I, page 476. They can be summarized as follows, viz.:

1. The magnesian limestones of Ohio are of exceptional purity in so far as the absence of iron, alumina and silica is concerned.

2. They slake into the whitest and most impalpable powder.

3. They require more time for slaking than the limes of the former division actually need, but not more after all than it is well to give these first-named limes.

4. They are much slower in setting than the true limes. More than twice as many bricks can be laid with one spreading of the mortar made from them than with mortar made from the true limes. They allow more rapid and economical work on this account, and are greatly preferred by masons and plasterers on this account.

5. They can be burned much more easily than the limes of the first section. The percentage of fuel saved has not been determined, but it is considerable.

6. In durability, the mortar of the magnesian limes is certainly at no disadvantage. The masonry and brick work of the city of Springfield, for example, where none but magnesian lime has ever been used, will compare very favorably with similar structures, under equal exposure, in Columbus, where the lime heretofore employed averages nearly ninety per cent. of carbonate of lime.

The statements above made call attention to some of the leading characteristics of the two classes of lime now produced in the state. These statements are preliminary and provisional in some degree. The questions need a quantitative and final determination. It is a matter of great regret that the resources of the Survey were inadequate to the necessary experimentation in the preparation of the present chapter.

It will be shown in this chapter that Ohio is extraordinarily rich in dolomites of the highest possible degree of purity. A great deal of lime goes to market in which the total impurities will not aggregate one per cent. of the product.

In the other section, also, limes of unusual purity are produced on the large scale, but necessarily there is much greater difference between the several limes of the second list than of the first.

III. Centers of Production.

For convenience in description, the lime manufacture of the state will be described under four main divisions, as follows:

1. Southwestern Ohio—(*a*) Clarke, Greene, Miami, Shelby, Montgomery, Preble and Darke counties.
   Lime—Mainly dolomitic.
   Horizons—{ Niagara, Guelph division. / Clinton, small production.
   (*b*) Highland and Pike counties.
   Lime—Dolomitic.
   Horizon—Lower Helderberg.

2. Northern Ohio—Ottawa (in part), Sandusky, Seneca, Hancock and Wood counties.
   Lime—Dolomitic.
   Horizons—{ Lower Helderberg. / Niagara, Guelph division.

3. Northern Ohio—Erie and Ottawa (Islands and Marblehead).
   Lime—Calcareous.
   Horizon—Upper Helderberg.

4. Central Ohio—(*a*) Franklin county.
   Lime—Calcareous.
   Horizon—Upper Helderberg.
   (*b*) Marion county.
   Lime—Calcareous.
   Horizon—Upper Helderberg.

These divisions will be treated in the order named.

The facts pertaining to the first division were mainly collected for the Survey by Mr. Franklin C. Hill, of Yellow Springs. His description of the general conditions of lime-production in Southwestern Ohio, and especially of the modes of manufacture, will apply, with but little change, to other portions of the state. They are given here in his own words.

1. The Lime-Production of Southwestern Ohio.

(*a*) *Clarke, Greene, Miami, Shelby, Montgomery, Preble and Darke Counties.*

"In the counties of Clarke, Greene, Miami, Montgomery and Preble, lime-burning is carried on at many places, either as a separate business, or in connection with quarries of building stone. Men are yet in active business who remember seeing lime burnt by simply throwing surface stones, and bowlders from the drift, on to the top of log-heaps, which were being burnt to get rid of the surplus wood of the country, and after the fire died out, selecting those lumps which happened to be well burnt.

"As the value of wood increased and skilled labor became more plenty, kilns were built of simple, cheap construction. And although in the railroad centres patent draw-kilns of various kinds are used, yet some of these primitive kilns are even now in use.

"Two styles of kiln seem to have started so nearly together that it is hard to say now which is the elder. In one, about three-quarters of a conical pit was built of stone, either in the side of a bluff, or backed up by earth piled against it. The ash-pit was under the middle, and stones of the most refractory kind to be had were

laid across it as grate-bars. Over this the fire-arch was built of limestone. More stone was piled above, and then the open side of the pot was closed with a wall of stones and lime. All this work, of course, had to be repeated at every burning. Several of these kilns are still in use at Cedarville, and other places.

"In the other form a rectangular kiln of stone is carried up far enough to enclose the lower half of the pot, an arched doorway being left in one side, large enough to answer at first for a fire-door and afterwards to admit men to remove the lime. The upper part of the pot was sustained by a revettement of logs, like the base of a log cabin, lined with packed earth.

"From these two forms the steps to the most approved patent draw-kiln are easy and natural. One radical change should be noted, the pot, at first widest at top, becomes in the draw-kiln widest at bottom, to ensure against choking as the mass descends. In all pot-kilns much time and heat are lost by cooling the kiln after each firing. In the draw-kilns the fires are built in arched chambers of fire-brick at the sides of the kiln near the bottom. The stone is thus never directly above the fire, but is reached by the blaze drawing in from the sides. The limestone is simply dumped into the top of the kiln, and settles down by its own weight. At intervals, regulated by experience, a draw-hole at the bottom is opened, and as much lime as is done is shoveled out from below the mass of unburnt stone, which at once settles down and brings another portion within reach of the fire, whilst fresh stone is placed on top.

"Of course, in starting a draw-kiln the first drawing brings out the stone which lay below the fire and was not burnt. This is carried up and thrown on top. Afterwards the kiln can be burnt without stop until it wears out—perhaps ten or twelve years—with no loss of time or heat. Workmen estimate the time required for stone to pass through the kiln at from thirty to forty-eight hours. Those burners who prefer not to work on Sunday, close all fire and draw-doors on Saturday night, lute them with lime, and thus hold everything in check until midnight of Sunday.

"As to the merits of the different styles of kiln used, much difference of opinion exists. Large operators usually prefer some one of the draw-kilns, although many successful burners continue to use the old pot-kilns. There are several kinds of patent draw-kilns in use, as Monitor, an iron kiln, and the stone structures of Page and of Corey; and many burners have changed the details of these kilns to suit their own taste or experience. Though it is conceded by all that the draw-kilns give the greatest yield of lime in proportion to the fuel, yet some assert that in falling through the kiln the lime is so badly broken and ground up that much is air-slaked and lost. Where the demand for lime is steady, and the draw-kilns can be worked to their full capacity, there seems to be no doubt of their superiority; but as the demand slackens, or becomes irregular, they lose value, and a point is soon reached when their use becomes ruinous. As a matter of fact, we see a firm who have used draw-kilns for years with great success, building pot-kilns when they establish a branch business, and we see little old log-topped pots steadily burning within three miles of a Monitor that controls the trade of a railroad center.

"Quite a large number of brands of fire-brick are in use for lining the kilns, and opinions are somewhat divided as to their merits. There seems to be little reason to doubt that those made in Albany, N. Y., of clay from South Amboy, N. J., are the best, though their high cost limits their use. Some, who claim to be experts, use them in the parts most exposed to heat, and cheaper grades as the distance from the fire increases.

"Wood is used as fuel in all kilns in these counties, and exclusively in nearly all of them. Many operators assert that a wide-spread prejudice against coal-burnt lime prevents their use of coal; but those who do use it deny this, and claim that a considerable saving is made by mixing the two fuels.

"Little advance seems to have been made since the Report on Clarke county was written (see Vol. I, page 479) in utilizing the ashes from lime kilns. Now, as then, the soap-boilers use a part of them, and those lime-burners who are also farmers use some on their own lands, but large operators find their ashes hard to dispose of.

"The business of getting out building stone is often, though by no means always, carried on by the same parties as the lime-burning. This results naturally from the lime rock lying on top of the building stone, from which it must be removed if either rock be needed. This fact greatly complicates the problem of computing the cost of either product. To get at the building stone the lime rock must be removed, even if thrown away, as is now done on a large scale at Covington, Miami county, by several parties, and all expenses must then be charged to building stone. Should there ever be a greater proportional demand for lime than now exists, these waste-heaps will yield a cheap supply to the then owner. Meanwhile, in the next quarry a Monitor kiln constantly absorbs a large quantity of the cap rock, giving a lime product whose cost must be largely dependent on circumstances, or perhaps opinion, changing with the relative thickness of the two varieties of stone, and with the market demand for the two products.

"The majority of burners state that at present the lime costs them about ten cents per bushel (of seventy pounds) at the kiln, when wood is the only fuel, and those who use coal in part estimate a saving thereby of from one to one and a half cents per bushel. Naturally those quarries which are placed on a hillside above a railroad, where the stone will fall by its own weight into the top of a draw-kiln, which delivers the lime on a level with a car on a siding, have great advantages over those where the stone must be raised to a great height by horse power, and whence the lime must be distributed in wagons over common roads. And yet the lime supply of the city of Dayton is largely drawn from kilns situated seven miles away, whence it is drawn in wagons. And the quarries there lie many feet below, and many rods distant from the bottom of the kilns—common pot-kilns of small size—to the top of which most of the stone must be hauled in carts. At these kilns wood costs as much as elsewhere, yet they compete successfully in the city with the great Springfield kilns, whose lime passes through Dayton by rail on its way to a market. One advantage, however, these country kilns have in the city trade. Their wagons take the lime from the kiln directly to the consumer, and it thus escapes rehandling.

"A large majority of the kilns in these counties burn the Niagara magnesian limestones, and the small minority use the purer carbonates of lime known as Clinton rocks. Those using Niagara stone will, therefore, be first spoken of. The characteristics of both rocks will be found fully described in the former volumes of the Ohio Geological Survey. The product of the Niagara rocks is known to the trade as a 'cool' lime, and is much preferred by those masons who are accustomed to its use. Its mortar is easier to use than that made with the hot lime of the Clinton, as it can be worked with less haste, owing to its setting more slowly. When once set it very soon hardens, and then shows great endurance. No ordinary nail can be driven into the joints of brickwork laid with it, after it has stood two years; in the walls of Antioch College, which was built in 1852, the mortar has, for at least twenty-five years, been harder than the pressed bricks it holds together. There is, doubtless, some difference in the value of limes from different quarries of the Niagara rock, though not so much as is often thought or stated. The limes may require slightly different treatment, but when their secrets have been found out by experiment, they will all give good results.

"In the earlier years of the city of Dayton the so-called Dayton stone was used as a source of lime, and old residents state that at the present time the mortar made from it leaves the bricks easily, and crumbles under the hammer, when old buildings

are destroyed. This may be partly the fault of inexperienced or careless masons. Perhaps they failed to 'dip,' or wet, the bricks when laying them up. An ordinary brick, after being thoroughly dried, will absorb about a pint of water (one pound, averaged by actual trial), a fact which few are willing to accept without proof. When dry bricks are laid in mortar they absorb much of the water from it, and 'kill it,' before it can set, and thus weaken it greatly.

"Complaint is often made against this lime for 'pipping.' Certain small pieces of lime in the 'putty-coat' fail to slake until after the plaster is on the wall. When they do slake, as they will when they have absorbed the right amount of water, though it may not be for years, they burst out and ruin the wall surface. Much discussion has arisen as to the cause of this trouble, and its remedy. The idea of its being caused by the use of coal (Ohio Geological Report, Volume I, page 476) is easily disposed of, by stating the well-known fact that desperate cases occur at Yellow Springs where no coal is used. A more probable cause is to be found in the structure of the stone itself, in which the small quantity of silica that is always present seems to be unequally distributed through the mass. (In some quarries this silica is found in distinct layers.) The silicious masses may resist the action of water longer than the other parts of the lime, and yet they will slake when their time comes.

"A more practical question is, how to prevent pipping, and that is easier of solution. If the putty-coat be allowed to lie for some days, say from seven to ten, before using, as it should be, no pipping will occur. Should this method be thought too slow, the slush must be run through a fine seive, as is commonly done by the Springfield plasterers, and the Chapel of Antioch College, which was plastered by Springfield men some seventeen years ago, may be quoted as an example of the success of this method.

"The Clinton rock yields a hot lime not liked by masons accustomed to that of the Niagara, but much preferred by paper makers and gas works. One firm use this rock in other ways, which will be spoken of in discussing their quarry."

The principal lime-production of the several counties of this group will now be briefly described:

Clarke County.

The chief lime-production of Clarke county is within the limits of Springfield, and in its immediate neighborhood.

On the left banks of Buck Creek, within the city limits, are the Pettigrew quarries. One Monitor kiln, with a daily capacity of 200 bushels, is in operation here. The cap-rock from which the lime is burned has a maximum thickness of about twenty feet. Its composition varies somewhat in different parts of the quarry. Within the range of the property, it is locally replaced in part by flinty beds. The proprietor believes that a difference is found in the quality of the lime produced from different sections of the cap-rock that is now worked, a tendency to "pip" being found at one extremity of the workings.

The building-stone courses occur in beds of twelve, four, eight, eight and four inches in descending order, covering four beds of cutting stone, the thicknesses of which respectively are twelve, ten, six and eight inches. Underneath blue and silicious beds are found.

The value of the building stone is $1.25 per perch. The cutting stone sells for a good deal more, but the market is not always ready for what is produced.

The lime burned here finds a local market only, and the kiln is not making more than half time. The industry is reaching its natural limits, in this locality. Wood for burning costs $2.75 per cord, and railroad facilities are entirely wanting.

The composition of the lime is already sufficiently established. The analyses of 1870 revealed the great purity and excellence of the Springfield dolomites. They are repeated here. A single analysis, made for the Survey in 1886 on a large number of samples, and thus showing the average composition, is also presented:

1. Middle bed. *Wormley.*
2. Upper bed. *Wormley.*
3. Average. *Lord.*

	1	2	3
Carbonate of lime	55.40	53.90	54.13
Carbonate of magnesia	41.48	41.90	44.37
Alumina and oxide of iron	1.80	2.70	0.56
Silicious matter	1.30	1.40	0.65
	99.98	99.90	99.71

On the right bank of Buck Creek, and also within the city limits, are the quarries and the single Monitor kiln of George H. Frey. The same general statements that were made in reference to the previous interest are also applicable here. The supply of rock is running short in these quarries, and production will not long be maintained. Mr. Frey claims a production of sixty-six bushels of lime to one cord of wood. This rate is as high as any in the district.

The composition of the stone is indicated in the following analysis:

1. Middle bed. *Wormley.*
2. Upper bed. *Wormley.*
3. Average. *Lord.*

	1	2	3
Carbonate of lime	54.70	54.70	53 88
Carbonate of magnesia	44.93	42.37	43.79
Alumina and oxide of iron	0.20	1.00	0.39
Silicious matter	0.10	1.50	1.55
	99.93	99.57	99.61

The wonderful excellence of the Springfield stone is fully attested by these figures.

The kilns located on the left bank of Mad River, three miles below Springfield, owned by Moore & Company, are the largest and best known sources of Springfield lime.

In these quarries there are thirty feet of cap-rock (maximum), and fourteen feet of building stone. The main courses are, in descending order, six, nine, six, four, four and twelve inches in thickness respectively. Beneath them three valuable courses of cutting stone, of sixteen, eighteen and twenty-two inches respectively, are found.

Three Corey kilns are in operation here, and one kiln built by the company on a plan of its own. The kilns are advantageously situated, with reference alike to charging and shipping. In the last named kiln there are three fires 120° apart, with draw-hole on one side. The daily capacity of this kiln is rated at 400 bushels. Its consumption of wood for this production is 6.15 cords, showing an average of sixty-five bushels of lime to one cord.

The composition of the Moore lime is shown in the following analysis of an average made up from many fragments of the rock as burned. The analysis was made by Professor Lord:

Carbonate of lime	53.51
Carbonate of magnesia	44.96
Alumina and oxide of iron	.42
Silicious matter	.66
	99.55

There is but little purer rock than this worked in the state.

On the same side of the river, and one-fourth of a mile below the Moore kilns, is the draw-kiln of Jacob Hankle, near Snyder's Station. The natural conditions are similar to those last described, but the development is just begun.

The Fintz quarries and two draw-kilns are also located on the right bank of the river, and nearer town than those already described. The production is not urged at the present time, but the lime is as good as the best, as is shown in the appended analysis: (*Lord*)

Carbonate of lime	53.92
Carbonate of magnesia	44.99
Alumina and oxide of iron	.37
Silicious matter	.68
	99.96

On the right bank of Mad River are three lime-producing quarries, within a distance of three miles below Springfield.

The first quarry is that of J. B. Crane & Brothers, (formerly the Sintz quarry.) There are two draw-kilns connected with this quarry, but they are not in constant operation.

John McCarty, next below, has one square draw-kiln, with a capacity of 350 bushels *per diem*, requiring four cords of wood. If the figures pertaining to this production are carefully given, they are the best of the field.

More account is made of the building-stone market than of the lime market, at the present time. The composition of the lime is as follows: (*Lord*)

Carbonate of lime	53.77
Carbonate of magnesia	44.76
Alumina and oxide of iron	.39
Silicious matter	.59
	99 51

Holcomb's lime-production, that is found next below, is by far the largest and most important in the district, with the single exception of the Moore kilns.

His quarries are in admirable order. All of the work has gone forward methodically, and with reference to the permanence of the industries concerned. As in the other interests previously described, the products of the Holcomb quarries are divided into limestone and building stone. Of the former, or cap-rock, there is an average thickness of twenty-five feet, which is now exposed in a wall 400 feet in length. It has been worked back from the kilns so as to leave a floor of building stone, 100 feet wide, which is level with the two draw-kilns that are located directly on the line of the N. Y., P. & O. R'y. The building stone is worked as required, from the floor above named, towards the railroad level, the best of facilities for quarrying and loading

being maintained. It is about twelve feet thick, in eight courses. Below it there is a second but inferior bench of lime rock, fifteen feet in thickness.

The admirable statistics furnished by Mr. Holcomb, for the use of the Survey, in Volume I, are no longer applicable to the lime interest of this region, from the fact that there is universally blended with it now the production of building stone. The latter interest is often the more important of the two, as has been already shown in several instances. The analysis of the limestone, and also of the building stone, from these quarries, is appended.

The figures are as follow:

1. Holcomb's limestone. (*Lord.*)
2. Holcomb's building stone.

	1	2
Carbonate of lime	53.44	50.13
Carbonate of magnesia	44.49	40.64
Alumina and oxide of iron	.54	.96
Silicious matter	1.37	7.37
	99.84	99.10

This enumeration completes the list of lime manufacturers in Clarke county, so far as the main supply for the general market is concerned.

Greene County.

Precisely the same conditions exist here that have been already described. Lime is burned in the large way at but two points in the county at the present time, viz., at Cedarville and Yellow Springs.

Cedarville, situated on the main line of the Little Miami Railroad, seven miles above Xenia, has long been noted for the quantity and quality of its lime-production. The Niagara limestone is uncovered here in the bed and banks of Massie's Creek, and its tributaries, on quite a large scale. Many acres of stone are accessible, with but very little outlay in the way of stripping. The stone is very porous and soft, but it makes a lime of the highest excellence in its grade.

D. S. Irvin is the principal producer at the present time. He uses three draw-kilns, built on Page's patent, but slightly modified, and two open-front pot-kilns, but all are not worked to their full capacity. Wood

costs from $2.00 to $2.50 per cord. Mr. Ervin counts fifty-eight bushels of lime to one cord of wood in the draw-kilns, and fifty bushels to the cord in the pot-kilns. He has worked in all, thirty-five feet of stone, at the deepest point in his quarries. The upper half is thin and irregular in its bedding, while the lower is much more regular and solid. Both kinds are burned together, and no difference in quality is recognized. The building stone has never yet been reached, but it cannot be very far below the present depth of the quarries. The stone is raised by steam haulage on an inclined plane from the quarries, and all the economies that are necessary to success in this manufacture, under present conditions, have been introduced here.

Messrs. Orr and Iliff have each four pot-kilns, located one-fourth of a mile from the railroad, and are running when the market warrants. The proper conditions have been found but infrequently of late, and are not likely to return. Lime can be manufactured more advantageously by a system quite different from that which prevailed a score of years ago.

The limestone was sampled from two of Mr. Ervin's quarries, and analysis gives the following results: (*Lord*)

Carbonate of lime	53.95	53.90
Carbonate of magnesia	44.62	44.58
Alumina and oxide of iron	.57	.53
Silicious matter	.58	.88
	99.72	99.89

The quality is seen to be of the same high grade already reported in the Springfield stone. Physically, the Cedarville stone can be readily distinguished from the Springfield stone, but chemically they are identical.

A well-established business in lime-production has been maintained in Yellow Springs for many years. The rock is exposed in bold cliffs along the gorges of the Little Miami River, and its tributaries, and can be quarried here to excellent advantage, and to any required extent. The sections embrace, as at Springfield, both limestone and building stone. The cap-rock is about twenty feet thick, and twelve to fifteen feet of building stone have been worked below it without reaching the bottom of this division.

Irvin & Company are the only parties now producing lime at this

point. They have a single kiln of the old type. It contains 1,500 bushels of lime. The stone is raised by a portable engine from the quarry to the kiln, the latter being located on the railroad. The lime is of the same high grade of magnesian limes that has been already described. In fact, the stone is almost chemically pure dolomite. Its composition is shown below:

1. Selected samples of limestone. *Wormley.*
2. Average of limestone. *Lord.*
3. Average of building stone. *Lord.*
4. Blue building stone. *Wormley.*

	1	2	3	4
Carbonate of lime	54.75	53.98	50.75	51.10
Carbonate of magnesia	42.23	44.56	41.86	41.12
Alumina and oxide of iron	2.00	0.51	0.76	1.40
Silicious matter	0.40	0.72	5.65	5.40
	99.83	99.77	99.02	99.02

There is no limit to the production of lime of the purity denoted in the analyses above quoted in Greene county, so far as easily-accessible rock is concerned. Fuel is growing scarcer and higher in price, year by year, but if coal were once successfully introduced in the burning, this county could meet all the demands of southwestern Ohio for all time to come.

Montgomery County.

The production of lime in Montgomery county is limited to a single point, viz., Bartholomew Wilson's kilns, in section seventeen, Wayne township, where the business has been going on without interruption for more than forty years. The lime has no railroad outlet, but is wagoned into Dayton, where it has long had an almost undisputed supremacy in the home market. The lime has proved through this long experience so good that no one has felt justified in asking for better, though the wagon-haul raises the price above some of the limes that reach the city by rail.

Mr. Wilson works sixteen feet of cap-rock, which reaches down to and rests upon the building-stone courses, the latter being left undis-

turbed. He has three common kilns, of 500 to 1,000 bushels' capacity, n each of his two quarries. Wood costs him $2.60 per cord. He counts ıforty to fifty bushels of lime to one cord. His production has reached as high as 120,000 bushels per year, but the present demand does not call for more than 75,000 bushels. Even this amount is very likely to be, in part, replaced by the cheaper lime of precisely the same grade that the various railroad centers supply.

One section of the quarries has been found to yield a lime that "pips" in the wall. It has long been rejected as a source of lime. An nalysis of it is appended. Mr. W ilson's explanation of its unsatisfactory character, viz., that it carries silicious particles, seems to be borne out by the analysis.

The composition of this famous lime is shown below. The excellence of the product is attested by the condition of the work that for the last forty years has been built with it in Dayton, as well as by the accompanying results:

1. Best lime, first quarry. Average. *Lord.*
2. Best lime, second quarry. " *Lord.*
3. Rejected stone. " *Lord.*

	1	2	3
Carbonate of lime	54.30	54.47	51.97
Carbonate of magnesia	43.69	44.73	42.07
Alumina and oxide of iron	.83	.47	1.13
Silicious matter	.80	.39	4.00
	99.62	100.06	99.17

In the average rock of the second quarry, the surprising fact is to be observed that the total impurities are considerably less than one per cent. There is no better stone of this kind in the state, but there is a great deal that is just as good, and if any pre-eminence belongs to the lime, it must be derived from some peculiarities in burning rather than from the character of the native rock. Probably the lime will be found to agree very closely in its working with other limes of the same composition.

Miami County.

The lime-production of this county is not important, though the possibilities are great.

At Covington, Joseph Rhule is burning lime in one Monitor kiln, the daily yield of which is 250 bushels. Wood costs him $2.25 to $2.50. Preference is given to beech. Hickory and sugar maple are rejected, as giving too much coal. One and one-half cords are required to burn 100 bushels of lime. Lime is sold at twelve cents per bushel on the cars.

The composition of Rhule's limestone is as follows: *(Lord)*

Carbonate of lime	54.14
Carbonate of magnesia	44.90
Alumina and oxide of iron	.40
Silicious matter	.85
	100.26

The quarry shows twenty feet of cap-rock or limestone, two feet of yellow "well stone," four feet in six to twelve-inch courses, underlain by ten feet of building stone, ranging from twelve to thirty inches in thickness.

In the other quarries of the town, several of which are worked on quite an important scale, the cap-rock is treated as waste. Twelve feet of this division need to be removed to reach the building-stone courses. The first courses are of medium quality, but underlying them are seven courses of excellent building stone. A thirty-inch course found here is considered one of the most valuable limestones of the state. It is in no respect inferior to the Dayton stone.

The only remaining production of this part of the county is found in Clayton township, north of Covington, where Oliver and Samuel Nichodemus each burn, during the season, in small pot kilns, one to each farm, twelve to twenty kilns of 150 bushels. The rock employed is the surface Niagara stone, and the quality of the lime is doubtless of the usual excellence.

In Bethel township, at the village of Brant, Thomas Corey burns lime in two small pot-kilns on the Dear farm. The production is about 500 bushels per week. It could easily be doubled if the markets would allow. The price of the lime is twenty cents at the kiln. Twelve cords of wood, costing $2.50 per cord, are required for the burning of 500 bushels of lime.

The Brant lime has an excellent reputation through all the neighborhood, and a good deal of it has been wagoned to Dayton. The subjoined analysis shows that the lime fully deserves its good name. The analysis was made by Professor N. W. Lord:

Carbonate of lime	54.3
Carbonate of magnesia	44.01
Alumina and oxide of iron	.40
Silicious matter	.32
	99.10

These figures show as pure and excellent a magnesian lime as can be produced anywhere in the world.

The Piqua lime, which is burned from the Clinton limestone, will be found described on a subsequent page.

Preble County.

The lime-production of Preble county is principally confined to two points, viz., New Paris and Lewisburg.

The manufacture has long been carried on at New Paris on quite a large scale. The lime has had an excellent reputation, and has been widely distributed, especially by the railroad, to the west of Richmond, Indiana. Claims of unusual character were known to be made for the lime, but they were discarded on the ground that the same Niagara cap-rock, which has been so largely used in surrounding counties in this interest, was the sole source of the lime at this point also. The series as disclosed here was, however, known to be considerably abbreviated, and in other ways transformed, as compared with the typical sections of Greene and Clarke counties. (Geology of Ohio, Volume III, page 409.)

It has so happened that no analysis of the New Paris lime has been made for the Survey until the preparation of the present chapter was begun. The results of this analysis are unexpected and surprising. They show a lime that has departed widely from the common type of the upper Niagara, or Guelph division, the composition of which cannot be distinguished from that of the Lower Corniferous limestone. The figures will be given presently.

James Dwyer is burning lime in one Page kiln, the capacity of which is counted 1,200 bushels per week. The limestone quarry shows twelve feet of cap-rock, but is not worked down to the building stone.

Thomas J. Smith uses two Page kilns, situated in different parts of his extensive quarries. The section found in a large part of his workings is about as follows:

Limestone, four feet,
Rotten limestone, three feet, } cap-rock.
Limestone, four feet,
Building stone, six and eight feet.
Shale or soapstone, three feet (Niagara shale).

At the bottom of this column the Clinton limestone is found. As intimated above, the section has been greatly reduced, and in fact almost atrophied in this instance.

Mr. Smith uses coal, in connection with wood, to a small extent in burning his lime, standing almost alone in southwestern Ohio in this respect.

He claims a saving of one to one and one-half cents per bushel on the lime thus burned. He believes that kilns can be so constructed as to admit of the use of coal to the exclusion of wood. Of course this can be done here as in the old world, but no one has been entirely successful thus far in the attempts in this part of the country.

The chemical character of the New Paris lime is shown in the appended table:

1. Dwyer's upper limestone. (*Lord.*)
2. Dwyer's lower limestone. (*Lord.*)
3. Smith's lower limestone. (*Lord.*)

	1	2	3
Carbonate of lime	61.33	67.51	67.00
Carbonate of magnesia	37.68	30.84	29.26
Alumina and oxide of iron	.37	.38	.56
Silicious matter	.61	1.23	2.21
	99.99	99.96	99.03

These limes are seen to be very free from impurities In this respect they rank as high as the dolomites already described. They deserve the name that they have gained of being hotter and stronger, in the usual sense of these words, than the limes previously described with which they come into competition.

Lime is burned on quite a respectable scale at Lewisburg, and in the immediate neighborhood, by Messrs. Disher, Turner & Weaver.

Christian Disher's kilns, three in number, of the old type (pot-kilns), are located one mile east of Lewisburg. Wood costs $2.50 per cord, and one cord is claimed to make fifty bushels of lime. The lime is sold at the kiln at twenty cents per bushel. Much of it is wagoned to Eaton, and to surrounding villages. The annual production oscillates between 30,000 and 50,000 bushels. Mr. Disher makes use of the ashes resulting from burning, on his farm, and derives great advantage therefrom.

Wm. Turner has two small pot-kilns, and produces about 10,000 bushels of lime per year. To burn a kiln that yields 200 to 215 bushels, he uses five to five and one-half cords of wood.

The composition of the Lewisburg lime is shown in the appended table:

1. Disher's lime, selected sample. (*Wormley.*)
2. Disher's lime, average. (*Lord.*)
3. Turner's lime, average. (*Lord.*)

	1	2	3
Carbonate of lime	55.20	54.58	52.70
Carbonate of magnesia	43.28	43.93	43.96
Alumina and oxide of iron	.60	.45	.94
Silicious matter	.60	.89	1.31
	99.68	99.85	98.91

Darke and Shelby Counties.

These counties possess unlimited capabilities in the way of lime-production, so far as the availability of the Guelph beds is concerned, but neither is producing anything more than local supplies at the present time. The Sidney lime was at one time an important factor in the Cincinnati market, but the production has been abandoned altogether.

Its composition is shown in the appended analysis: (*Wormley*)

Carbonate of lime	55.00
Carbonate of magnesia	42.92
Alumina and oxide of iron	1.60
Silicious matter	trace

The Darke county limestone is peculiar in its excessive proportion of carbonate of magnesia. The latter element even exceeds the carbonate of lime in some instances, as is shown in the following table:

1. Bierly's quarry, near Greenville. (*Wormley.*)
2. Gard's quarry, near Greenville. "
3. Northrop's quarry, near New Madison. "

	1	2	3
Carbonate of lime	44.69	51.30	51.70
Carbonate of magnesia	50.11	45.72	45.26
Silica, alumina and oxide of iron	4.60	2.20	2.70
	99.31	99.22	99.66

The Greenville lime is greatly valued where it is used, on account of its whiteness and mildness. The production is not, however, large, and is not likely to be maintained under present conditions. The stone mainly lies low in the ground, and cannot be quarried with due advantage.

There is a small production of lime from the Niagara dolomites at Kirkwood, Shelby county. A patent kiln of 250 bushels capacity is in operation here. About 10,000 bushels of lime were burned here in 1887. The stone is easily accessible, and of considerable thickness. Production is restricted only by the cost of fuel. It could be indefinitely expanded.

The Clinton Limes.

The limes that have thus far been described are all, without exception, derived from the Guelph beds of the Niagara limestone. All are seen to agree in being dolomites of the highest possible quality, with the single and unexpected exception of the New Paris lime.

Within the geographical limits that have now been traversed, there is a small production of a different kind of lime, from a distinct horizon viz., the Clinton limestone. This production must be briefiy described. It is found at three localities, viz., near New Carlisle, Clarke county; near Osborn, Greene county, and at Piqua, Miami county.

The lime manufactured formerly by John Brown, near New Carlisle, and at present by Brown & Sons, at the same place, is well known through all that section of the state as one of the purest and hottest limes of southern Ohio. The larger part of the product is consumed by paper mills, and for this use find it unequaled. Much of the stone is as white as marble. It is ground in considerable amount as a substitute for marble in the production of carbonic acid. It is, also, used as a body for sealing wax, in small amount.

The lime is burned with wood and coal combined, about eighteen tons of coal and fifty cords of wood being used every month. Wood costs

$2.50 per cord. One Monitor kiln, re-enforced by smoke stacks, produces the lime, the annual product being 25,000 to 30,000 bushels.

The lime is sold at eighteen cents per bushel, the price not being gauged by the prices of the magnesian limes by which it is surrounded on all sides. The Brown quarries constitute one of the most remarkable bodies of rock in the state, as is shown in the following table:

1. Selected sample—(*Wormley*).
2. Average of quarry—(*Lord*).

	1	2
Carbonate of lime	95.60	96.80
Carbonate of magnesia	3.93	2.07
Alumina and oxide of iron	.40	.29
Silicious matter	trace	.83
	99.93	99.99

A quite similar body of rock of the same geological age is worked on a small way near Osborn, Greene county, by George Haddock. The kiln is, however, located in Clarke county. The lime is burned exclusively for the supply of the Dayton gas company. The kiln yields 400 bushels and requires seven to eight cords of wood, worth $2.50 per cord. The lime is sold for twenty-three cents per bushel. About six feet of stone are worked in the quarry which lies on the summit of the ridge. The stone from one part of the quarry has been rejected as of unsatisfactory quality. Analysis shows this to be a purer and better rock, though by a very small difference, than the accepted stone. The figures showing composition are appended:

1. Best rock, Haddock's quarry—(*Lord*).
2. Rejected rock, Haddock's quarry—(*Lord*).

	1	2
Carbonate of lime	97.09	97.14
Carbonate of magnesia	.82	1.21
Alumina and oxide of iron	.36	.41
Silicious matter	1.64	.70
	99.91	99.46

The third source of Clinton lime for the general markets is that produced by Cofield & Company, on Mrs. Harrington's farm, just below Piqua. The kiln is a draw-kiln of modern fashion, and yields 300 bushels per day. The product is mainly taken by paper mills. One cord of wood is counted as producing fifty bushels of lime. The cost of the wood is $2.50 per cord. Surface rock is mainly used thus far in the kiln. The composition of the stone is shown in the following analysis: (*Lord*)

Carbonate of lime	95.03
Carbonate of magnesia	4.35
Alumina and oxide of iron	.26
Silicious matter	.45
	100.09

This analysis reveals the remarkable excellence of the best types of the Clinton formation in southwestern Ohio It is only the best phases that are selected for the lime manufacture, and they are almost invariably burned, when burned at all, for special purposes. The Clinton limes make no figure in the mortars of the districts in which they are found. If they were wanted for such purposes, the supply would be forthcoming. Many other locations can be pointed out beside those already mentioned, in which an equally choice quality of the formation is to be found.

(6.) *Lime Production of Highland and Pike Counties.*

An important source of lime in southern Ohio has long been found in the Lower Helderberg limestone on the north side of Highland county. This formation attains here its greatest excellence, and quarries of great value have been opened at Greenfield, Lexington and other points on the line of the Cincinnati, Washington and Baltimore railway (formerly M. & C. railway). The Greenfield quarries are among the most extensive and valuable limestone quarries in the state. The remarkable evenness of bedding and uniformity of composition in the stone found here gives to it a great advantage for many uses over any other stone in this part of Ohio. It is coming to be known as by far the best stone for curbings, crossings and footing courses that the western half of Ohio can supply.

Its composition has been spoken of as uniform and constant. It is this point which renders it specially available for lime production. Throughout its whole extent as developed in this county, it is a very pure dolomitic limestone, of the same type as the underlying Guelph, which has been already described. The only qualification that deserves to be made is with reference to balls of flint that occur very sparingly.

in the stone and to nodules of black-jack or blende (sulphide of zinc), that occurs with like infrequency. Aside from these insignificant exceptions, the entire products of the quarry are used; the sound stone for the various lines of service already indicated and all of the fragments, for the lime-kilns that are connected with the quarries. The consequence is that the quarries are always swept and garnished. No accumulations of waste disfigure them and obstruct future operations, but everything that is broken out of their rocky walls is turned to account. The train that carries the sound stone to market will also carry a car or two of the best of lime to the same destination, the latter representing the spalls and fragments made necessary in the disengaging of the various grades of paving and structural stone.

The conditions of the lime manufacture that is based on this stratum are thus seen to be different from any already described in southwestern Ohio.

Elsewhere the lime-producing stratum is entirely distinct from the building stone, and needs to be removed to expose the latter, but here, while the great interest is in the building stone, the lime-production is directly subsidiary to it, giving value to all the portions that elsewhere are a source of trouble and expense.

The lime has not the whiteness of the best grades of the Niagara dolomites. In all other respects it is almost their exact counterpart, but it falls a little below the highest standard of excellence.

The composition of the Lower Helderberg limestone of this section is shown in the following analyses, quoted from Report of Progress, 1870:

1. Rucker's quarries, Greenfield. *Wormley.*
2. Wright's quarries, west of Greenfield. "
3. Wright's quarries, Lexington. "
4. Pope's quarries, Leesburg. "

	1	2	3	4
Carbonate of lime	53.67	49.90	54.10	49.76
Carbonate of magnesia	42.42	44.87	41.77	45.77
Alumina and oxide of iron	1.30	1.00	2.20	.90
Silicates of lime and magnesia	1.44	2.98	.....	2.88
Silica	1.00	1.45	1.60	.69
	99.83	100.00	99.67	100.00

In other portions of Highland county the Guelph limestone exhibits its highest excellence. In the vicinity of Hillsboro, it yields a lime that for mildness, whiteness and general excellence is unsurpassed by any limestone of this class in the state or elsewhere. In fact, its quality does not admit of improvement, within the lines of composition indicated.

In Pike county, also, throughout the westernmost townships and in the Sunfish Valley farther to the eastward, the Lower Helderberg limestone yields a dolomitic lime of the same purity and excellence as that furnished by the Guelph division of Highland county. The possibilities of cheap lime-production in the Sunfish Valley are unequaled in the state, barring the all-important matter of transportation.

2. The Lime-Production of Northern Ohio.

(*a*) *Ottawa (in part), Sandusky, Seneca, Hancock and Wood Counties.*

Character of lime—Magnesian.
Horizons of lime—{ Lower Helderberg.
{ Guelph division of Niagara.

The surface-rocks of many thousands of square miles of northern Ohio consist of magnesian limestones that are almost absolutely free from the usual impurities of these rocks. These limestones belong to two great formations, viz., the Guelph division of the Niagara limestone, and the lower beds of the Lower Helderberg limestone. The latter are often left in areas of small extent and thickness upon the uppermost beds of the Niagara limestone. There is a difference in the bedding and fossils of the two formations, in such instances, by which they can be readily separated, but in chemical composition they are identical. The Guelph beds, through all of the counties named above, are very nearly uniform in composition. There is a much smaller range of variation than is found, for example, in the same series of rocks in southwestern Ohio.

The Lower Helderberg limestone has two or three times the thickness of the Niagara, and it is only the lower portions of this great sheet that are found as pure dolomites. The middle and upper beds are much broken in composition, large deposits of gypsum interrupting the limestone beds. The higher portions of the series are for the most part hard, blue limestones, containing a considerable percentage of the usual silicious and clayey impurities of this grade of limestones. To this last statement, however, there are some conspicuous exceptions.

Chemical analysis shows no differences between the limestones of this group that are worked for lime manufacture in northern Ohio.

Local variations can be marked, it is true, in every field, to a small extent, but the differences are as great in any extensive quarry as are the differences between the quarries of different counties, so that, in the general way, the entire series can be regarded as one body of rock.

There is, however, a firm belief in the several lime-burning centers that different localities yield different grades of lime, even where chemical analysis reveals no distinction. This belief does not always take the usual form, in which each manufacturer counts his own lime clearly the best, but the most observant and most experienced producers often find ground for believing that the rock of particular localities possesses particular excellencies. It is a matter of regret that these questions could not have been settled on an adequate practical and scientific basis for presentation in this discussion, but, as already stated, all these magnesian limestones of northern Ohio are substantially one. Their chemical unity will appear in the analyses to be given.

Ottawa County.

Genoa.

This has long been one of the main centers of lime-production in this part of the state, operations having been begun here more than twenty years ago. It still holds a leading place in the manufacture. It is situated on the old road of the Lake Shore and Michigan Southern Railway, and has the advantage of long lines in the distribution of its products. Both of the geological horizons named above are exposed here, and, in a few instances, both occur in the same quarry. The Drift is very light in this vicinity, and next to no stripping is needed in reaching the rock.

The parties now engaged in burning lime are the following, viz.:

A. L. Newman, three kilns.

Wyman, Gregg & Co., three kilns.

Wm. Habbeler, two kilns.

Frank Holt, one kiln.

In addition to the kilns named above, which are all draw-kilns of modern construction, there are scattered around near the quarries numerous pot-kilns of the earlier day, in various stages of dilapidation, some of which could, however, be easily made serviceable in case any emergency should arise.

The Newman quarries can be taken as representative of the district. They are worked to a depth of twenty feet. The stone exposed in this section is divided into two divisions, viz., the cap-rock, which is also called the honey-comb rock, and the bottom-rock. The maximum thick-

ness of the former is ten feet; of the latter, twelve feet. The honey-comb rock is also divided into an upper and lower portion, the upper portion frequently cutting out the lower by overlap. The honey-comb rock is of the sort called unstratified. It gets its name from the numerous cavernous spaces that it contains. No lines of deposition are apparent in the mass. It is immediately covered by the thin and even beds of the Lower Helderberg, or Waterlime division, carrying the characteristic fossil, *Leperditia alta*. These layers come into view in adjacent openings of the rock. The strata exhibit many marks of minor disturbance, being in this respect in marked contrast to the beds of the same age in southern Ohio, where a high degree of regularity of structure prevails.

The boundary between the cap-rock and bottom-rock is very distinct in the quarries. The last-named division is found in rather ill-defined layers or beds. It is highly fossiliferous, *Trimerella*, *Monomerella*, *Fentamerus*, being found in it in great perfection as internal casts, together with a score of other well-known fossils of this prolific horizon. The bottom-rock carries numerous small deposits of heavy spar in its fissures, which are sometimes blackened by the action of the heat of the kilns.

In the adjoining quarries of Wyman & Gregg, the Lower Helderberg limestone makes the surface-rock, and the bottom-rock of the Newman quarries is not reached at all in the excavations.

In the Habbeler quarries, a thin cap of Waterlime (Lower Helderberg) is found covering the honey-comb rock of the Newman quarries. The main lime-production is from the last named sheet.

The Holt quarries, which lie a mile east of the railroad, have yielded an enormous amount of lime during the twenty years in which they have been worked. Six acres have been quarried in this time down to the limits of convenient drainage. The average depth is about ten feet. The rock is wholly Guelph (Niagara), and the usual profusion of its characteristic fossils is found in it. The lime has the reputation of unusual excellence, and has long commanded permanent markets for itself.

The kilns used at Genoa are all draw-kilns of modern type, and several of them are provided with steam-hoists that raise the stone from the adjacent quarries. They are all so situated as to have the advantages of excellent railroad facilities, except the last named, which has, however, thriven well without such advantages up to the present time. Steam drills are in use in the quarries, and steam pumps of necessity. The waste of the quarries in small stone is considerable. It makes a medium quality of road metal.

Wood is universally used in burning the lime. A trial of coal was

once made here, but it was not counted successful. The supply of wood has heretofore been abundant, but the longer hauls necessitated by twenty years of active operations begin to affect the price. It can still be bought, however, for $1.50 per cord. Six cords of wood are counted sufficient to burn 100 barrels of lime. A barrel holds two and five-eighths bushels, and seventy pounds are counted to the bushel. The cost of the barrel ranges from sixteen to twenty cents. Hard wood is mainly employed, red-oak, elm and cottonwood being the main reliance. A cooper shop is a necessary appendage to a kiln.

The Genoa lime has every excellence of the class to which it belongs. There are no whiter, milder, purer dolomitic limes anywhere than those which have made the name of this town famous through northwestern Ohio and Michigan.

Slight differences can be observed in the limes from the different sources already described. The lower portion of the cap-rock of the Newman quarry is to be counted as the most perfect type, according to the results of analysis, of the dolomites of the state. The entire lime of the cap-rock has, when fresh slaked, a very delicate pinkish tint, which is characteristic. The difference between it and the surrounding rock is, however, very slight, and would be entirely inappreciable in most practical tests. The bottom-rock is counted by the burners as "hotter" than the cap-rock, slaking quicker and being a little sandy, but it is impossible to find in the results of analysis any hints of such characteristics.

In the following table the composition of the limestones from the leading quarries is given:

1. Cap-rock, Newman. (*Lord.*)
2. Bottom-rock, Newman. (*Lord.*)
3. Main rock, Wyman & Gregg. (*Lord.*)
4. Main rock, Habbeler. (*Lord.*)
5. Main rock, Holt. (*Lord.*)

	1	2	3	4	5
Carbonate of lime	55.97	53.04	54.30	55.59	54.61
Carbonate of magnesia	44.27	46.01	45.14	43.67	45.05
Alumina and oxide of iron	.23	.51	.16	.42	.44
Silicious matter	.04	.22	.23	.28	.24
	100.51	99.78	99.83	99.96	100.34

There is no other record in the state that is quite equal to this. The magnesian limes reach their highest mark in the cap-rock of Genoa. It will be observed that the total impurities in limestone number one, of this table, are but one-fourth of one per cent., and in none of the Genoa limes do the impurities make an aggregate of three-fourths of one per cent.

Lime is burned at several other localities in Ottawa county, in the large way, viz., at Clay Center, Rocky Ridge, and Limestone Station.

The quarries and kiln at Clay Center are owned by W. B. Scott & Company, of Toledo. A production of about 26,000 barrels of lime was reported for 1885. The kiln is located on the railroad, but the quarry is distant an eighth of a mile to the north. The rock burned here is exclusively the Guelph division of the Niagara. There is a face in the quarries of about fifteen feet, and all of the rock exposed is counted fairly uniform in quality. A peculiarity of this quarry is the large amount of barite, or heavy spar, that is found in pockets that are irregularly and sparingly distributed through the rock. Certain points in the quarry are abandoned at times on account of the prevalence of the spar. The latter is frequently found filling the cavities of the large fossils that occur here, and particularly the shells of *Megalomus Canadensis*. The only points in the state where the shells of this remarkable fossil occur are in Ottawa county, and they are especially well-shown at Clay Center. The character of the lime is very similar to that already reported.

The lime-production at Rocky Ridge is in the hands of Messrs. Kingham and Smith, each of whom makes use of the lowest beds of the Lower Helderberg limestone. The location of the quarries is such that eight to fifteen feet of the latter formation are found here, resting upon the so-called Salina formation of the earlier reports. A foot or two of carious limestone, charged heavily with petroleum and asphaltic matter, underlies the Lower Helderberg formation in this immediate vicinity. The latter is known as the cap rock. In Dr. Kingham's quarries a maximum of fifteen feet of it is found; in the Smith quarries, it does not exceed eight feet. The stone lies in a disturbed condition, the prevailing pitch being north thirty-five degrees east, and the rate of descent varying between two and four degrees. Dr. Kingham has opened, at a single point, a still lower stratum, which consists of a blue, highly-crystalline, non-fossiliferous rock that is said to burn into a superior lime.

The average composition of the Rocky Ridge limestone (Lower Helderberg), as sampled in Dr. Kingham's quarry, is as follows. (*Lord.*)

Carbonate of lime	54.10
Carbonate of magnesia	44 27
Alumina and oxide of iron	29
Silicious matter	.87
	99.52

These figures show that the lime is of the same excellent type as that already described.

At Limestone Station, on the Wheeling & Lake Erie Railway, a well-located and well-equipped lime plant has been recently established, the most modern and complete, in fact, in the county. It consists of two kilns of the Monitor pattern, with fire-brick walls, supported by red brick lining. The kilns have a daily capacity of seventy-five barrels each. The entire works are under one roof, and thus admit of the greatest economy of labor.

The Waterlime, or Lower Helderberg limestone, is found here with the usual excellence of the bottom courses of this formation. In fact, it weathers to a lighter color here than at most other points in the region. It is covered with a very light coat of drift, and there are considerable areas in the vicinity in which the stone constitutes the surface. The quarries, which are worked to a depth of eleven feet, are opened directly adjoining the kilns, and steam is employed in hoisting the stone, as well as in keeping down the water. Wood is plenty on all sides, and a supply for several years is assured at $1.00 per cord, the quality of the supply being unusually good.

The average composition of the limestone is shown in the following table: (*Lord*)

Carbonate of lime	54.12
Carbonate of magnesia	44.79
Alumina and oxide of iron	.25
Silicious matter	.29
Total	99.45

With all the advantages here indicated, viz., the cheapest and best fuel of the field, the most modern and efficient plant and a limestone as good as the best, it is evident that lime can be burned here to advantage as long, at least, as anywhere in this section of the state, the single but important exception of the natural gas towns being recognized.

It is obvious that the possibilities of lime-production in Ottawa county are absolutely unlimited, so far as the most accessible supplies of the purest of dolomites is concerned. The limitations come on the side of fuel, and in connection with transportation.

Sandusky County.

Magnesian limes are burned in the large way at Fremont, Gibsonburg and Woodville.

At Woodville, H. Rancamp & Company are producing 175 barrels of lime per day in two draw-kilns. Their consumption of wood amounts to twelve to thirteen cords per day. The annual production of the kilns for 1885 was 40,000 barrels. The markets of the lime are almost entirely to the southward. A considerable amount is used in Pittsburgh and Bellaire in glass manufacture, to which it is declared to be especially adapted. The section of the quarry from which the limestone is taken is twenty-two feet. All belongs to the Niagara formation.

The average composition of the limestone is as follows: (*Lord*)

Carbonate of lime	53.50
Carbonate of magnesia	45.79
Alumina and oxide of iron	.39
Silicious matter	.31
Total	99.99

At Gibsonburg, there are also three kilns, established on well-ordered quarries of the Niagara limestone. The character of the lime agrees, in all respects, with that already described from this section.

Much the largest lime-production of the county comes from Fremont, where a magnesian lime of an excellence unequaled, except in the contiguous areas of northern Ohio, has long been produced. The stone that is burned belongs to the basal portion of the Lower Helderberg formation. It seems probable that it is from the lowermost beds, which are separated from the Niagara limestone only by the thin shale parting of greenish color that has passed for some time in our geology under the name of the Salina shale. The quarries are worked to a maximum depth of thirty feet. There are considerable areas in which no stripping is required, the limestone rising to the surface.

The quarrying and burning are carried on upon a considerable scale by Noble & Company, and by Gottron Brothers.

The increasing cost of wood at Fremont has subjected this industry to a growing disadvantage in competition with numerous other points in the country around, in supplying lime to the general markets. The price of wood has risen here to $2.50 per cord, while other kilns in the vicinity are furnished, as has been already shown, with wood at $1.00 per cord. Competition becomes more and more difficult under these conditions. If there were any decided superiority in the limestone quarried

at Fremont, relief might be found; but while this limestone is as good as the best, there are several thousand square miles of limestone, a score or more of feet in thickness, that can furnish lime indistinguishable from the Fremont lime in any respect whatever.

The search for natural gas at Fremont has been continued with great persistency and great outlay, by Noble & Company, largely with reference to their important interests here in lime-production. The home supply, it seems safe to say, in view of this costly exploration, is inadequate to lime-burning on a large scale. Gas brought in by the Northwestern Company, from the gas fields of Hancock county, is now introduced by this firm into their kilns, with great satisfaction, as is understood.

The composition of the limestone, from the two prominent sources of Fremont lime, is given below:

1. Fremont limestone, Noble & Company. (*Lord.*)
2. Fremont limestone, Gottron Brothers. (*Lord.*)

Carbonate of lime	54.06	55.65
Carbonate of magnesia	45.20	42.29
Alumina and oxide of iron	.27	.43
Silicious matter	.74	.35
	100.27	98.72

Seneca County.

The magnesian lime-production of Seneca county is chiefly centered at Tiffin, Kansas, Bettsville and Fostoria. A small quantity of lime of the calcareous division has been for some time manufactured at Bloomville, from the outcrop of the Upper Helderberg limestone at this place.

Bettsville produces a lime of excellent repute, from quarries of Niagara limestone that are worked to a depth of twenty or twenty-five feet. There are two draw-kilns in operation here.

Kansas has a single draw-kiln, which was supplied for some time with the loose rock that lay in bowlders over the surface of the country. The lime produced has the usual character and excellence of the horizon, viz., the Niagara limestone.

Lime has been burned for local use in small pot-kilns in and near Tiffin from an early day. Both the Niagara and Waterlime are exposed

here, and the lime manufactured possesses the characters that have been already found in the strata that belong at this line of junction.

The largest production of the county is at Fostoria. A fine body of Niagara limestone, advantageously situated for quarrying, is exposed here. The average composition of the stone used for lime-burning is as follows: (*Lord*)

Carbonate of lime	56.41
Carbonate of magnesia	41 98
Alumina and oxide of iron	.28
Silicious matter	.42
Total	99.09

These figures show that there is little or nothing left to be desired in the character of the limestone. Like all the other representatives of the formation within this group of counties, it makes a close approach to perfection, as a source of dolomitic lime.

The parties engaged in the production are John A. Bradner, Esq., and Dwight P. Lloyd. Wood has now been superseded by natural gas, as a fuel in the kilns. Two and one-half cords were used under the former system of burning in making seventy barrels of lime, the wood costing $1.50 per cord. Much of the lime finds an eastern market, particularly along the line of the Baltimore and Ohio Railway. It has been used, with approval, in the glass manufacture of eastern Ohio and western Pennsylvania, and later in the important glass manufacture that has recently sprung up in the new gas-fields of Ohio.

Gas from the pipe lines has recently been introduced into the kilns by Mr. Bradner, and its use is reported as giving great satisfaction.

Wood County.

Within the limits of Wood county, lime is now burned for the general markets at the following points, viz., Bowling Green, Portage, Rising Sun, and Luckey. It is produced at several other points in a smaller way. The entire production is derived from the Niagara limestone, which is exposed in many square miles of the county as literally the surface rock, no accumulations whatever of drift covering or obscuring it. The possibilities of lime-production in the county, so far as the supply of a pure dolomite is concerned, are absolutely without limit. The Niagara limestone is known to have substantially the same character for 200 feet or more in thickness. Samples of the drillings taken from the deep wells recently sunk at various points within the county, agree fairly well in composition with the surface rock. This is shown in the following table:

1. Niagara limestone, surface, Bowling Green. (*Lord*).
2. Niagara limestone, 210 feet deep, Bowling Green. (*Lord*).
3. Niagara limestone, 260 feet deep, Bowling Green. (*Lord*).

	1	2	3
Carbonate of lime	53.98	49.19	51.62
Carbonate of magnesia	43.25	40.31	44.08
Alumina and oxide of iron	0.40	.....	.....
Silicious matter	1.53	7.76	0.97
	99.16		

These lower portions of the stratum do not appear to be as pure as the surface rock, it is true, but it is quite likely that if there were exposed sections of the entire series, parts of it would be found as good as any that now makes the surface. This belief seems warranted by the character of the lower portions of the Guelph division in its outcrops to the southward.

As it is, ten to thirty feet of rock are easily accessible at numberless points along railroad lines within the county, which will furnish an inexhaustible supply of the magnesian limes for which this portion of northern Ohio is justly famous.

At Rising Sun, located on the Columbus, Hocking Valley and Toledo railway, an important lime-production has been maintained since the railroad was first opened. The leading producers of Ottawa county, as soon as the new lines of road were established through Wood county, took possession of the more promising portions of the field, and thus guarded the older centers for a while against a disastrous or destructive competition which could easily arise from the more abundant fuel and cheaper stone which the new districts would at first command.

Wyman, North and Company, of Genoa, built up and still control the Rising Sun lime-production and also the production of Luckey Station on the Toledo and Ohio Central railway.

At Rising Sun, the Niagara limestone rises to the surface on a large scale. A foot or two of the uppermost beds are generally so discolored as to be rejected, but aside from this, there is no waste whatever except in small stone, which can generally be got rid of for road metal. The rock is found in rather massive sheets, which break very irregularly. The quarries are worked to a depth of twenty-two feet below the surface. Strong springs of water are found within this depth, but no great

expense is needed to keep them down. The lime was first burned in pot-kilns, but the main reliance is now on a draw-kiln with a daily capacity of a little more than 100 barrels. The kiln is drawn three times in twenty-four hours. Six cords of wood are required to produce 100 barrels of lime, the price per cord ranging from $1.20 to $1.50; it is generally $1.25. The cost of barrels is eighteen cents, counting in the labor of filling. The cost of producing a barrel of lime on this basis is about forty-two cents.

The lime is not quite as white as Genoa lime, but it still commands a good market. It also finds its way to the glass works of western Pennsylvania, but its best use is as a plastering lime.

The composition of the stone, sampled from the entire face of the quarry is given below: (*Lord*)

Carbonate of lime	53.21
Carbonate of magnesia	45.37
Alumina and oxide of iron	.63
Silicious matter	.57
	99.78

The lime interest of Luckey Station, which dates back only five or six years, is in part, in the same hands as the Rising Sun production, belonging to Wyman, Gregg & Co., of Genoa. They have established a draw-kiln here in which about seventy barrels of lime are burned each day. Messrs. Krotzer and Rothenbuhler also burn lime on their respective farms, in old-fashioned kilns. The former makes use of two kilns with a combined capacity of about 1,300 bushels, for burning which twenty-one to twenty-two cords of wood are required. The cost of wood at present is $1.25 per cord. Mr. Rothenbuhler burns his lime in a 500-bushel kiln, which requires ten to twelve cords.

The lime is counted peculiarly excellent, if degrees can be recognized where all is so good. The Luckey lime is as white as the best phases of Genoa lime and is famous for the putty coat it yields. It is said to show no chip cracks whatever. Tested between two plates of glass, it proves as smooth as butter.

The composition of the Luckey limestone, as sampled from the largest quarry, comes fully up to the standard, but the figures do not reveal any ground on which claims of peculiar excellence can be justified. The results of analysis are as follows: (*Lord*)

Carbonate of lime	54.20
Carbonate of magnesia	44.44
Alumina and oxide of iron	.35
Silicious matter	.43
	99.42

It will be observed that these figures approach the typical figures for dolomite a little more closely than any of the analyses already quoted.

The lime-production of Bowling Green and Portage remains to be described in this connection. The leading facts have been already given, in the account of the development and utilization of the natural gas supply of these towns. (Pages 162-5.) It is upon this supply that the new industry is established.

Bowling Green now has two thoroughly-equipped lime-producing plants, and Portage, one. Each plant includes a quarry, two patent kilns, and excellent shipping facilities. The composition of the Niagara limestone in this district has been already given on a preceding page, but to facilitate comparison, it will appear here in its proper place. Carefully sampled, ten feet of W. S. Thurstin's quarry, at Bowling Green, gave the following results: (*Lord*)

Carbonate of lime	53.98
Carbonate of magnesia	43.25
Alumina and oxide of iron	.40
Silicious matter	1.53
Total	99.16

These figures do not stand for the highest possible phases of the Niagara limestone, but they represent a lime of the best of the Springfield or southern type, and good enough for every use. It has found its way already to distant markets, competing with the limes of the southern counties in Cincinnati and elsewhere. When first put upon the market, there was a good deal of complaint of underburning for a part of the stone and of overburning for other portions. The wood-burned lime took advantage of this defective product, and was able to regain a good many of the markets from which the cheaper product had begun to exclude it. But experience soon showed to those who were trying the new fuel, the way of safety and success, and gas-burned lime of thoroughly approved quality is now taking its place everywhere in the markets. It has come to stay, as long as natural gas stays. The cost of the one element of fuel is reduced, by the use of gas, from two to nine cents per bushel, at the Bowling Green rates, as compared with the cost of production elsewhere in the state. At Portage the disparity is even greater. Mr. McMahan first drilled a gas well, which yielded a vigorous supply. He then built near by it two draw-kilns, to obtain their fuel from the well. The well was cheaply drilled, and thus far has required no additional outlay whatever. If the flow is maintained for

several years, one of which has already passed, it is obvious that the fixed charge for fuel will shrink to an insignificant figure.

Conditions like these are revolutionary. It seems impossible for wood-burned lime, and particularly that of the magnesian variety, to retain its hold in this portion of the state against such odds. If the companies manufacturing lime by the use of gas were ready to maintain prices and enjoy for a while the extravagant profits which they could in that case command, the evil day might be postponed for a little while; but with the promise of profits so large, the manufacture would be sure to grow so rapidly as to speedily overstock the market, and competition would necessarily arise within the ranks of the producers. The lime-producers who use natural gas in calcination will, for the present, undersell the wood-burned lime as much as they need to, in obtaining a market. The price of lime will fall still further, when vigorous competition arises in the ranks of the new producers.

Hancock County.

Lime is burned on the large scale, at the present time, at but one point in the county, viz., at Findlay. Two establishments here are turning out lime in quite large quantities. The Barnd kilns are located on the southeast side of the town, on a prominent ridge of the Lower Helderberg limestone, that passes through the county. The two or three pot-kilns located here, that have long supplied the local demands of Findlay with a lime of approved quality, after natural gas was discovered, were forthwith connected by a small pipe line with a well drilled near by for this special purpose. No change was introduced into the manufacture, except in the one element of fuel. So far as known, the Barnd kilns are the only kilns of the old type, in the state, into which gas has been introduced.

Mr. Barnd claims that the quality of the lime is unchanged by the use of the new fuel in burning. He finds none of the difficulties reported by the draw-kilns in regard to overburning or underburning, at least, no new difficulties introduced by the change of fuel.

The face of the quarry, as it is here worked, is about eight feet. The stone is not entirely homogeneous in character, and some selection is necessary. The horizon of the stone is near the bottom, but not at the very bottom, of the Lower Helderberg division.

The composition of the approved quality is given below (1), and also the analysis of some of the courses that are rejected as making a very inferior lime (2). The results of analysis are as follows: (*Lord*)

	1	2
Carbonate of lime	53.88	49.62
Carbonate of magnesia	43.79	40.94
Alumina and oxide of iron	.39	1.16
Silicious residue	1.55	8.00
	99.61	99.72

The failure of the latter sample to make a marketable lime is sufficiently explained by its composition. If this composition could be depended on as constant, it would be easy to adapt some mode of burning to the stone that would produce a hydraulic lime of more or less value. No constancy in composition is to be expected, however.

The character of the lime is seen to be good, though not reaching the extreme purity that has been reported from a few localities in northern Ohio. The lime is highly approved in Findlay and through the surrounding country.

A modern plant, consisting of two draw-kilns, which has been established in the town during the last year by C. H. Hall, Esq., is now producing gas-burned lime successfully. The stone burned is the Lower Helderberg limestone, which is found at the depth of a few feet below the surface. It is likely to agree closely with the Barnd stone already reported in composition.

Lime has been burned for a railroad market for the last few years at Carey, in Wyandot county. The stone here used is the Niagara limestone in one of the whitest and purest phases that it assumes in the state. The lime is of the highest possible quality, the total impurities falling below one per cent. The lime has reached the Columbus market, where it has displaced for use in the "white coat" of the plasterers, the Columbus lime to some extent.

In Bath township, Allen county, the lower portion of the Waterlime (Lower Helderberg series) is burned for lime on quite a large scale by Mr. G. W. Fetters, the product of his kilns finding its entire market in the adjacent town of Lima, where it is used both for mortar and in the extensive strawboard works that are established here. The composition of the stone used in burning, as carefully sampled from the ten feet of the quarry on which the main dependence is placed, is as follows: (*Lord*)

Carbonate of lime	53.69
Carbonate of magnesia	45.00
Alumina and oxide of iron	.14
Silicious matter	1.18
	100 01

These figures show the Fetters lime to have the ordinary excellence of the formation from which it is derived. The upper beds of the series are, in this vicinity, hard, blue and impure, and consequently are not at all used in lime manufacture. By proper selection, hydraulic limes and natural cements could both be obtained from these sources, but it is not probable that the latter could be manufactured at a profit as against the great advantages of Louisville in this regard.

The larger centers of production of the magnesian limes of the state have now been described. There are many hundreds of points besides, where the series already treated of are found near the surface or are exposed in ravines, at which lime is burned for local use. It has been made to appear in this review that the western half of Ohio is extremely well supplied with dolomitic limestones that are almost chemically pure, and that the manufacture of the highest possible quality of magnesian lime can be indefinitely expanded so far as the supply of proper stone is concerned. Whatever limitations there are, are connected with fuel and transportation.

3. Northern Ohio.

Erie and Ottawa Counties (in part), including Marblehead and Kelley's Island.

Lime—Calcareous division.
Horizon—Upper Helderberg limestone.

Under this head, the lime produced from the Upper Helderberg limestone of the Marblehead peninsula and Kelley's Island is to be described. This center of production is one of the oldest, largest and, in every way, most important in the state.

While all of the lime manufactured in this vicinity belongs to the calcareous division, and while this division attains here a much greater importance than at any other point in Ohio, it is still true that a considerable variety of composition is included in it. The carbonate of lime ranges from seventy to ninety per cent. in the different portions of the formation, and the carbonate of magnesia from ten to twenty seven per cent. in the same divisions. The total impurities, which are mainly silicious, range from one and five-tenths per cent. to three per cent. in the better grades of the stone.

To render intelligible the facts of the lime-production, it will be

necessary to briefly review at this point the geology of the stratum concerned.

Geological Order and Chemical Composition.

The Upper Helderberg limestone of this part of Ohio, which is also known as the Corniferous limestone, is the northward termination of the main belt of this age in the state. It extends from Pickaway county on the south, through Franklin, Delaware, Marion, Wyandot, Crawford, Seneca, Huron, Erie and Ottawa counties to Lake Erie. It is also continued across the lake, through Kelley's, Middle and Pelee Islands, into Canada. The trend of its outcrop is a little east of north.

No one natural section in this part of the state exposes the entire thickness of the stratum. The longest single sections are found on Point Marblehead and Kelley's Island.

The Marblehead section will be first described. About forty-five feet of the lowermost beds of the Upper Helderberg formation are found on the eastern end of the Peninsula, resting upon the Lower Helderberg limestone. The breadth of the upper limestone, in an east and west line, nowhere exceeds four miles. In a north and south line, it extends almost entirely across the peninsula. The Lower Helderberg limestone is found in its place, below the limestone in question, throughout most of the area which the latter occupies. The bottom courses lie fifteen or twenty feet above the lake on the Lakeside grounds, and eastward from there as far as the James quarries. They dip gently to the east and south, and in consequence of this fact, they soon fall to the lake level, which they reach just beyond Roesling's dock. From this point, the stratum descends slowly and, in the main, steadily as far as Ohlemacher's quarries. Here only the upper beds of the western sections are found, above the level of the lake.

Two divisions of the formation are universally recognized in the quarries of this district, an upper and a lower division, which are approximately equal in thickness. The upper is commonly known as the cap-rock, or shell-rock, but it is also styled, from some of the uses to which it is put, flux-stone and pier-stone. It has a thickness of about fifteen feet. This cap-rock is a light-colored, thin-bedded limestone, peculiarly rich in fossils. Very thin, white, silicious crusts often cover the latter. The most common, or at least the most characteristic, fossils of this division are,

Onychodus sigmoides.
Spirifera gregaria.
Spirifera duodenaria.

Spirifera acuminata.
Strophodonta (several species).
Orthis livia.
Productella spinulicosta.
Paracyclas accidentalis.
Euomphalus.
Favosite corals.
Cyathophylloid corals.
Crinoidal fragments.
Bryozoa, &c.

The small spheres of the foraminiferal *Saccamina Eriana, Dn* are also very abundant and characteristic.

In composition, this division averages about ninety per cent. of carbonate of lime, and somewhat less than ten per cent. of carbonate of magnesia. The impurities are mainly silicious, and generally exceed two per cent. It is fairly represented in the accompanying analysis of the eight and one-half feet of cap-rock from the Hartshorn quarry :

Carbonate of lime	89.20
Carbonate of magnesia	9.64
Alumina and oxide of iron	.37
Silicious matter	1.00
	100.21

The lower division is known as the bottom-rock. It, also, has a thickness of about fifteen feet, but the upper boundary is not sharp and definite. It is a much heavier-bedded stone than the cap-rock, and visible fossils make a smaller percentage of it. What fossils there are, are sometimes rendered conspicuous by a reddish stain that covers their surfaces. The more common, or at least the more characteristic, forms of the lower division are, the heads of *Macropetalicthys Sullivanti*, the large *Strophodontas*, *Atrypa reticularis* (large form), *Conocardium trigonale*, *Favosites* and other corals. A few large-chambered shells are found here, mainly species of *Gyroceras.*

The stone of this division is also available for building stone of high grade. Dimension stone, in particular, is quarried here on the large scale at times. When it is so quarried, all of the spalls or fragments are used in lime-production.

The composition of the so-called bottom beds differs in a well-marked way from that of the cap-rock already described. The average composition of the eleven feet quarried for lime at the Hartshorn quarries fairly represents this division. It is as follows: (*Lord*)

Carbonate of lime	78.60
Carbonate of magnesia	19.79
Alumina and oxide of iron	.18
Silicious matter	1.55
	100.12

These two divisions do not, however, exhaust the section of the Devonian limestone of Marblehead. They comprise all the elements of economic value, and consequently but few exposures have been made of the remaining fifteen feet that separate the "bottom-rock" of the great quarries from the Lower Helderberg (Upper Silurian) limestone. The beds of this interval are disclosed in a few natural sections, and they have been cut through in draining some of the large quarries. They grow progressively richer in magnesia and poorer in lime as they are followed downwards. Flinty courses also occur in them, especially in the upper portion of this subordinate series. The analyses of the lowermost five feet (No. 1), and, also, of the five feet that are found from ten to fifteen feet above the lower boundary of the formation (No. 2), are given in the appended table. (*Lord.*) For comparison, the figures representing the two divisions above described are also repeated, No. 3 being the bottom-rock, and No. 4 the cap-rock :

1. Limestone, five feet above base.
2. Limestone, fifteen feet above base.
3. Limestone, twenty-five eet above base.
4. Limestone, thirty-five feet above base.

	1	2	3	4
Carbonate of lime	57.98	64.52	78.60	89.20
Carbonate of magnesia	35.57	28.83	19.79	9.64
Alumina and oxide of iron	.65	.45	.18	.37
Silicious matter	3.85	6.48	1.55	1.00
	98.05	100.28	100.12	100.21

If the Lower Helderberg limestone had, also, been represented in this table, the series would have begun with fifty-three or fifty-four per cent. of carbonate of lime, and forty-two or forty-three per cent. of carbonate of magnesia.

The longest connected-section in this particular district is found in the quarries now worked by Gamble & Company (formerly the M. B.

Fox quarry), and in ground adjacent thereto. The shore of the lake here consists of a low cliff of Waterlime or Lower Helderberg limestone, which appears in characteristic form, but with a very small supply of fossils. As the series is followed to higher levels along the quarry road, very thin and somewhat impure magnesian limestones terminate it. The separate layers are but an inch or two in thickness. They are non-fossiliferous, and in this, as in other respects, they exhibit unmistakable marks of their Lower Helderberg origin.

The exact junction of the Lower and Upper Helderberg limestones, which occurs just here, does not happen to be shown in any of the working points, but a small quarry of rough and rather heavy-bedded stone has been opened to the left of the road. Five feet or more are here exposed, the position of which is about ten to fifteen feet above the line of junction. This stratum contains a handsome showing of corals of the *Favosite* and *Cyathophylloid* families, several common species of *Strophodonta*, also *Conocardium*, and other Devonian forms. It is from this quarry that the samples represented in analysis No. 2, of the last preceding table, were taken.

To find the five or ten feet that intervene between this series and the Lower Helderberg limestone, or, in other words, to find the bottom course of the Devonian limestone exposed, we must follow the series eastward along the shore of the lake. It is dipping in the direction named, and just beyond Roesling's pier the exact junction of the two formations is shown. The lowermost five feet of the Upper Helderberg limestone that are found here carry many of the common corals of the formation, and rest directly on the thin-bedded and non-fossiliferous sheets of the Lower Helderberg series. It is from this point that the rock represented in analysis No. 1, of the last table, was taken. Though the limestone is now found fossiliferous, it has made as yet but little advance in composition upon the dolomitic type that prevails through the next underlying eight hundred or more feet of Lower Helderberg and Niagara formations. There is a gain, however, of three or four per cent. of carbonate of lime, and a corresponding loss of carbonate of magnesia.

Returning to the Fox quarries, we find in the drains that have been cut lakeward from the present main workings, the completion of the section from the bottom-rock of the quarrymen to the true bottom-rock of the formation, exposed in the opening already referred to upon the east side of the wagon road.

There are, probably, about five feet in this interval which is occupied, in ascending order, with a layer of flinty limestone, the flint occurring in white, irregular masses, followed by two beds of limestone,

alternating with two beds of shale or clay. The shale makes the floor of the main quarries.

The section, as worked, consists of twenty feet of limestone, equally divided between the two divisions already named, the cap rock and the bottom-rock. The entire section can be represented in diagram as follows:

Section at the Fox quarries.

Surface and waste rock	1–2 feet.
Cap-rock—thin stone, used for furnace-flux, pier-stone, road metal, &c., 85 to 90 per cent. carbonate of lime	10 "
Bottom-rock—heavy-bedded stone, used for lime and for building stone, 75 per cent. carbonate of lime	10 "
Shale and flint courses, floor of quarry	5 "
Lower quarry, 64 per cent. carbonate of lime	10 "
Bottom course, 57 per cent. carbonate of lime, (seen elsewhere)	5 "
Lower Helderberg limestone, to lake	15 "

These measurements show by the round numbers that appear that they are only approximate. The section is a comparatively long one, covering twenty-five rods or thereabouts, and it does not admit of nice determination.

Kelley's Island Section.

A similar section is found in the quarries of N. Kelley & Company, on Kelley's Island. The base of the Upper Helderberg series has here dropped to the water's edge, or a little below. From a reef eight or nine feet below the surface of the lake, unmistakable blocks of the Lower Helderberg limestone have been brought up. There are about fifteen feet of stone above the water level, which are nowhere exposed in the island, or, at least, in the vicinity of the quarries in question. The bottom of the quarries is in the flinty courses that have been already shown to constitute the floor of the Marblehead quarry section. This is followed by nine feet of stone, quarried to be burned into lime, the "bottom-rock" of the quarrymen; six feet of building stone; nine feet of "cap-rock," used for flux and pier-stone, surmounted by four feet of extra cap, so-called, which is a blue, highly-fossiliferous but very thin-bedded limestone. The last element is probably the lowest portion of the Sandusky section of the Upper Helderberg limestone. This consists of twenty-five feet or more of a blue, impure, very even-bedded limestone, well adapted for building stone, and also for street curbings and crossings. It carries a number of highly characteristic fossils, among which may be named a large *Tentaculite*, *Nucleocrinus Verneuilli*, and the scales, bones and teeth of fishes in quantity.

The section here described can also be arranged in tabular form, as follows:

Extra cap-rock—blue and thin-bedded limestone	4	feet.
Cap-rock—flux and pier-stone	9	"
Bottom rock ... Building stone	6	"
Bottom rock, used for lime-burning	9	"
Flint course	...	
Interval, not seen	15	"
Water of Lake Erie	...	
Lower Helderberg limestone, beneath surface	...	

It is unnecessary to multiply sections of this series. There are no exceptions to the order and character of the several beds that have been shown above.

It is thus seen that about twenty to thirty feet of the Upper Helderberg limestone are commonly quarried here, and that these twenty to thirty feet are divided into two quite distinct and well-bounded sections, the upper one of which is a very pure limestone, averaging ninety per cent. of calcite, and the lower one of which carries a much larger proportion of magnesia. It further appears, as will be shown in subsequent pages, that, except in a single instance where such selection is impossible, the lower section has been universally chosen by the lime-producers of the region as the source of their lime. They are obliged to remove eight to fifteen feet of the cap-rock in order to reach this lower stratum, and the cap-rock so removed is used for inferior purposes, or is even counted as waste. Moreover, the parties who carry away the limestone in bulk to be burned at Cleveland and other points along the lakes, invariably select the lower division. The reasons given for this selection are, that the bottom rock is more easily burned than the cap-rock, and that it makes a more desirable lime for general use. It is, also, more easily handled, as it is quarried in much larger blocks.

At the same time, all of the limes of this district are classed in the market as of one grade, and are sharply distinguished from the magnesian limes that are produced in the adjoining counties. This distinction does not appear to be fully justified. The lime-producers of this field deliberately pass by a nearly pure carbonate of lime, which they are obliged to remove at a large outlay, to make use of a stone that carries about twenty per cent. of carbonate of magnesia, claiming that they manufacture a much better article from the latter stone. That limes of very great excellence are produced from both cap-rock and bottom-rock, each in its own way, is certain, but if the lime derived from the latter is better than the cap-rock lime for any purposes, it seems fair to credit the increased percentage of magnesia with the im-

provement. The question then arises whether all of the improvement possible has been effected by the increase of carbonate of magnesia to twenty per cent. in the stone. Such questions cannot now be answered authoritatively, as has been already confessed, but the problems concerned doubtless admit of scientific and practical solutions which it is to be hoped will soon be reached.

A brief review of the several principal quarries and lime-producing plants of the district will follow these general statements in regard to the order and composition of the several elements of the Upper Helderberg limestone in Ottawa and Erie counties.

The Several Quarries and Lime-Producing Plants.

N. Kelley & Company's Quarries, Kelley's Island.

The section of these quarries which are the most extensive of the district has been already given on a preceding page. It consists of the four following elements, viz.:

1. Extra cap..... 4 feet.
2. Cap-rock..... 9 feet.
3. Building stone courses..... 6 feet.
4. Bottom-rock..... 9 feet.

Flint rock, underlying.

The quarries have been worked since the country was first occupied, and with great skill and energy. Not less than ten acres have been exhausted to an average depth of twenty feet. They supply four grades of stone, agreeing with the arrangement above given. The stone of No. 1, and also a good deal of the waste of the other divisions is used for macadamizing roadways, as far as the market calls for such material. The stone of the second division is chiefly used as flux for the Cleveland furnaces and the furnaces of the Lake Superior region. The waste of the other divisions is intermingled with this stone to quite an extent, and to the injury of the flux. The third division is worked for dimension stone, whenever the market calls for such. It can be obtained in blocks five feet thick, and of the largest size that can be handled. The fourth division is the only one that is counted on exclusively and uniformly for lime-production, but when the stone of No. 3 is not called for as building stone it also goes with that of the lower division, to the lime kilns.

In the light of these varied uses of the stone of the quarries, the following table of analyses will be found instructive. The several divisions, except the first, were carefully sampled, so that the average composition is shown in the analyses. A single block of the very hard

and tough blue stone of the upper cap gives the results credited to this division:

1. Composition of blue stone, extra cap. (*Lord.*)
2. Composition of cap-rock or flux stone. (*Lord.*)
3. Composition of building stone. (*Lord.*)
4. Composition of limestone. (*Lord.*)

	1	2	3	4
Carbonate of lime	97.28	87.10	89.16	77.22
Carbonate of magnesia	2.00	10.96	9.48	20.19
Alumina and oxide of iron	.27	.15	.20	.14
Silicious matter	.85	1.49	1.05	1.65
	100.40	99.70	99.89	99.70

It thus appears that stone ranging from ninety-seven to eighty-seven per cent. in carbonate of lime is successively rejected for lime-burning, and a division containing seventy-seven per cent. is universally preferred for this use. The hard blue stone of the upper-cap is seen to be one of the purest limestones of Ohio. It is not probable, however, that the figures here given would be found applicable to any large amount of stone.

The Cleveland furnaces report as the average composition of the flux that they obtain from this quarry:

Carbonate of lime	86.40
Carbonate of magnesia	11.49

These figures are seen to agree with the results of the analysis made by the Survey.

None of the stone raised from these quarries is burned on the island. It is shipped to Cleveland and the northern lakes, where it is burned on a large scale.

The Kelley quarries furnish valuable opportunities for observation and study in several lines of geological research.

Ripple-Marked Limestone.

During the summer of 1885 and also of 1886, a half acre, more or less, of the stripped surface of the limestone exhibited the finest series of ripple marks ever reported from the limestones of Ohio. As is well

known, limestones very seldom exhibit these marks of shallow water or shore origin. Such traces of the history of stratified rocks are mainly confined to sandstones and shales, but in this instance, a small tract was found covered with the unmistakable sculpturing of a very shallow sea. The crests of the wave marks were about eight inches above the bottoms of the furrows and about two feet apart. The direction of the crests and furrows was very regular, the lines bearing N. 14° W. The longest lines uncovered were 200 feet in length. On the northwestern side, the markings became confused and broke up into the "dimpled current mark" which is generally accounted for as the work of reflected waves.

Glacial Markings.

The glacial markings of this quarry have proved to be as interesting as any yet found in the state. The island itself is obviously a remnant that remains from a pitiless erosion. The ice that invaded and finally occupied Lake Erie in the Glacial period, undertook the work of cutting away and completely removing the Upper Helderberg cap of the great limestone series that makes the floor alike of the land and the water of this portion of the state. A large part of the work had been accomplished when the retreat of the ice cap was sounded. The mode in which the work was going forward is revealed in the uncovered quarry. The striæ left by the ice upon the surface of the limestone bear about S. 23° W. They belong to the earlier system of striæ and grooves which generally bear 10° or 14° W., or approximately north and south. The main joints of the limestone bear, on an average, N. 37° E., or what is the same thing, S. 37° W. When the ice struck a well-marked joint, left open by atmospheric waste, it would adopt and follow this line for awhile, cutting away much more easily the weathered edges of the joint than the solid rock elsewhere. Deep grooves were thus wrought out, six feet or more, below the general surface and fifteen to twenty feet in width. Great advantage was thus given to the erosive and abrading sheet.

On the extreme easterly end of the island, the striæ and grooves are found to bear S. 76° to 80° W., or approximately east and west. These belong to a later system of markings from those described above. All of the facts pertaining to these glacial markings have been worked out with great enthusiasm and sagacity by Capt. John Brown, Jr., of Put-in Bay.

On the northwest side of the island are the extensive quarries formerly owned and worked by G. W. Calkins and Company. The stone quarried here has long been burned on the large scale by the firm above

named in Cleveland, for the supply of the markets of the city and contiguous territory. The stone at present used in these Cleveland kilns is not exclusively derived from the island, but part of it comes from Marblehead, the quarries of M. B. Fox furnishing a considerable amount of the bottom stone of his quarry for this purpose.

The limestone used in the Calkins kilns in 1886 was carefully sampled and analyzed. The results of analysis are as follows: (*Lord*)

Carbonate of lime	71.17
Carbonate of magnesia	26.82
Alumina and oxide of iron	.40
Silicious matter	1.60
	99.99

The lime has an excellent and long established reputation in Cleveland, and a large part of the city has been built up by the mortar made from it or from other lime coming from the same sources. In composition it is seen to be an almost exact mean between the Niagara and Lower Helderberg dolomites and the hot limes of the cap-rock of Marblehead and Kelley's Island.

Within the last three years an energetic company, known as the Kelley's Island Lime, Stone and Transportation Company, has established itself on the north side of Kelley's Island, in the same range of rock that was formerly worked by Calkins and Company. Here eight draw-kilns have been built, and the manufacture of lime is going forward on a very large scale. It is to be regretted that the details of this important plant and the analysis of the limestone used were not obtained for this report. It is certain, however, that the conditions already described are found here without essential change or qualification. The production of lime for 1887, from this plant was not less than 75,000 barrels.

The following firms and individuals are now engaged in quarrying stone on the Marblehead Peninsula or in burning lime from the stone so quarried, either on the Peninsula or at Sandusky, or are engaged in both quarrying and burning:

Sloss Lime Co., lessees of the John H. James quarry.
Gamble and Co., succeeding M. B. Fox.
F. Roesling and Co.
Clemons and Sons.
Gager and Zollinger.
Judge Clemons.
Kunz and Johnson, succeeding Clemons Brothers.
Point Marblehead Lime Co.
L. B. Johnson and Co.
D. Kunz.
Ohlemacher Brothers.

McFall Brothers.

John H. Hudson, lessee of the Fletcher Hartshorn quarries.

Forty draw-kilns are owned and operated by the parties named above. The average production of the kilns is about 100 barrels of lime per day. During 1887, the total amount of lime burned here fell but little below 500,000 barrels. The figures can safely be put at 450,000 barrels. If the production of Kelley's Island is added, the aggregate will considerably exceed 500,000 barrels. Where these parties are not directly engaged in burning lime, they are shipping the stone to points more or less distant, at which much of it is so burned.

The section of the quarries of Gamble and Co. (formerly the M. B. Fox quarries) has been already given (page 746). A singular glacial groove has recently been brought to light in the working of the quarry. A deep channel was cut out by the glacier, along a line of joint, as described in the Kelley quarries, but here the excavation was carried on until the rock on the east side has become an overhanging wall. The depth of the channel is about eight feet below the surface of the rock. It was subsequently filled with material brought in from the north and especially by the thin-bedded Lower Helderberg limestones whose outcrop is found in that direction.

The Roesling Quarries.

F. Roesling & Co. have a large and excellently managed quarry interest. The company burns no lime on its own account, but ships the bottom rock for this purpose in the large way. Dimension stone, five feet in thickness, is also quarried by the company when demanded. As large blocks can be raised here as are ever required for any construction purposes along the line of the lakes.

Carefully sampled specimens of the cap and bottom-rock from these quarries were analyzed for the Survey, with the following results:

1. Composition of cap-rock, Roesling's quarries. (*Lord.*)
2. Composition of bottom-rock, Roesling's quarries. (*Lord.*)

*	1	2
Carbonate of lime	84.51	69.61
Carbonate of magnesia	13.31	27.43
Alumina and oxide of iron	.22	.90
Silicious matter	1.50	1.63
	99.54	99.57

The boundaries between the cap and bottom are not definite, and the beds are progressively richer in lime as we ascend in the series. These facts will explain the slightly discordant results of analyses.

The section of the quarries is, in the main, identical with that reported from the adjoining quarries of Gamble and Company. It is as follows:

Waste and shell rock		2 feet.
Cap or shell rock		11 feet.
Bottom-rock		10 feet.
White flint	8 inches	
Building stone course	14 "	
Shales, blue and drab	2 "	5⅓ feet.
Building stone course, blue	10 "	
Flinty courses	30 "	

The face or main joints of the quarries bear N. 40° to 60° E. On the whole they are quite regular, but they show many local curves. The end joints or cutters are much less persistent. Their general bearing will be included between N. 38° W. and N. 56° W.

The Clemons Quarries and Kilns.

The Clemons & Son's quarries show a much larger exhausted area than any others on the peninsula. They have been longest worked, and in the largest way. Recently a very complete equipment for lime-production, consisting of four draw-kilns, has been added by Gager & Zollinger. These quarries yield precisely the same lines and qualities of products, both in lime and building stone, that have been described in connection with the quarries already named.

The Kunz and Johnson Quarries.

The next group of quarries is that now worked by the firm named above. The quarries are part and parcel of the Clemons tract, having formerly been worked by the Clemons Brothers, and differ from the quarries previously described only in the fact that the eastward dip, referred to on a preceding page, has carried the series so low that not more than eight feet of the bottom-rock are left above the level of the lake.

The limestone is, in part, carried across the bay to Sandusky to be burned, and part is burned at the quarries. The Point Marblehead Lime Company has recently built four draw kilns adjacent to the quarries, while upon the main land the six kilns of L. B. Johnson & Company and the two kilns of D. Kunz are wholly or mainly supplied with stone from this source. The Point Marblehead Company is composed of Messrs. Johnson, Kunz, Dennis, and other parties.

The analyses of the cap-rock and bottom-rock of these quarries,

thoroughly sampled, are given below. The composition of the stone from Johnson's Island, formerly burned by L. B. Johnson, is also added:

1. Cap-rock, Kunz & Johnson's quarry, 6 feet. (*Lord.*)
2. Bottom-rock, Kunz & Johnson's quarry, 8 feet. (*Lord.*)
3. Bottom-rock, Johnson's Island. (*Lord.*)

	1	2	3
Carbonate of lime	81.48	73.61	69.58
Carbonate of magnesia	15.84	24 26	27.96
Alumina and oxide of iron	.40	.06	.32
Silicious matter	1.55	1.77	1.92
	99.27	99 70	99.78

The cap-rock from the Kunz and Johnson quarry is considerably lower in carbonate of lime than usual for this portion of the stratum. This fact is accounted for by the absence of the upper beds of the cap-rock from the section. It will be remembered that the cap-rock becomes progressively richer in lime to the top of the division.

The Ohlemacher Quarries and Kilns.

The firm of Ohlemacher & Company produces a much larger quantity of lime than any other single firm engaged in the business in the two counties now under consideration. The lime supplied by this company is also of a somewhat different grade from any other lime of the district, as is seen in the following analysis, made from a careful sampling of the limestone used in the manufacture:

Composition of Ohlemacher & Company's limestone. (*Lord.*)

Carbonate of lime	89.08
Carbonate of magnesia	8.34
Alumina and oxide of iron	.33
Silicious matter	1.51
	99 26

These figures indicate b-yond question that the cap rock of the other quarries is here used for the production of lime. How this comes about will be made apparent by the following statement:

The quarries of Ohlemacher & Company are located on the extreme southeastern outcrop of the Marblehead limestone. As the stratum dips

steadily to the east and south, this is the same as saying that it must be found lower here than anywhere else on the peninsula. How much lower it is will be seen by an inspection of the section of the quarry which is here given:

Waste-rock, pier-stone, &c.	1–4 feet.
Main rock, (cap-rock of other quarries)	7½ feet.
Shell	2 feet.
Bottom-rock of other quarries	2½ feet.
Level of lake and lower limit of workings.	

The main joints of the quarry bear W. 37° E. Translating the facts of the section into words, it appears that the entire limestone sheet has pitched steadily downwards from the outcrops on the peninsula first described, until only two and one-half feet of the bottom-rock are left above the level of the lake. The cap-rock is, therefore, the main resource of the quarries, and as far as the stone for burning into lime is concerned, it is either "this or nothing." If the bottom stone had been found in quantity enough to meet the demands of a large production, it is quite likely that it would have been chosen for this purpose, here as elsewhere. It is to be noted, however, that the cap-rock has a much more solid structure in these quarries than where it lies higher and has, consequently, been more exposed to atmospheric agencies.

As it is, the cap-rock is burned for lime only by this firm in northern Ohio, and thus a peculiar product is furnished by it. The Ohlemacher lime is, undoubtedly, the hottest and strongest of the entire field to which it belongs. Every other firm producing lime in the field could, however, produce a lime of exactly the same grade, if it chose to do so. Each one laboriously quarries and removes and sells for inferior uses, if it sells at all, the eight feet that yield the lime now described, in order to reach the milder and more magnesian limestone of the bottom-rock.

It is obvious that the limes of the district cannot be properly considered as a unit in such a sense, that what is true of one is true of all the rest.

The lime plant of the company consists of twelve draw-kilns, on the lake front in Sandusky. They are well located and well constructed. Several original appliances are embodied in their construction.

A recent experiment made here in the use of Lima oil for fuel, in the place of wood, deserves mention. The heat of combustion proved too high for the fire-brick lining of the kilns. It is now proposed to convert the oil into gas, by the Westinghouse process, and make use of

the latter in the kilns. The supply of wood is becoming yearly more difficult to maintain. To help out the failing supply, coal is used in almost all of the kilns of this vicinity to a greater or less degree. There is, probably, some saving of expense in the matter of labor connected with its use, but the principal reason for introducing it has been given above. Too large a proportion of it in burning the stone is thought to injure the quality of the lime, a tendency to chip-crack characterizing it in such circumstances. Notwithstanding the growing difficulty in obtaining wood, enough to meet the demands of a rapidly-expanding production, the price has not been allowed to become exorbitant in any respect. The average cost of wood for 1887 is reported at $2.35 per cord. A considerable part of the supply is brought from Canada.

John H. Hudson's Lime Plant.

The extensive quarries of Fletcher Hartshorn, now leased by John H. Hudson, are the most southerly and westerly of the Marblehead quarries. They also lie at a greater elevation above the lake than any other portion of the limestone on the peninsula. The section found here is as follows:

Waste rock, pier stone, &c	2 feet
Cap-rock, used for furnace flux, pier stone, &c	8½ "
Bottom rock, burned for lime	11 "
Interval—not seen—to level of bay, principally occupied by Lower Helderberg limestone	50 "
	71½ "

The analyses of the two main elements, the cap-rock and the bottom rock, have been already given, but they will be repeated here in their relation to lime production. The results were determined on carefully sampled specimens. To them will be added the analyses of a specimen selected as producing the best lime of the quarries, and also of a single sample examined by Professor Wormley in 1870.

1. Cap-rock of Hartshorn's quarries. (*Lord.*)
2. Bottom rock of Hartshorn's quarries. (*Lord.*)
3. Bottom rock of Hartshorn's quarries. (*Lord.*)
4. Bottom rock of Hartshorn's quarries. (*Wormley.*)
5. Cap-rock, Ohlemacher's quarries. (*Lord.*)

	1	2	3	4	5
Carbonate of lime	89.20	77.23	78.60	65.80	89.08
Carbonate of magnesia	9.64	18.85	19.79	27.95	8.34
Aluminia and oxide of iron	.37	.44	.18	3.30	.33
Silicious matter	1.00	2.65	1.55	2.70	1.51
	100.21	99.17	100.12	99.75	99.26

The fourth analysis does not represent the character of the lime now produced. The bed which yielded these figures must have been taken from the very bottom of the quarry. The second analysis can be depended upon as representing the present average composition of this lime. The cap-rock is seen to be almost exactly identical with Ohlemacher's limestone, the composition of which is reprinted in column five. This bed is, however, laboriously removed, much of it failing to find market, and the bottom rock only is used in the kilns. The ground of this selection has already been indicated, viz., the belief that the bottom-rock is burned more easily and makes a larger product for the fuel employed.

This lime represents the best grade of the ordinary Sandusky lime, the Ohlemacher lime constituting a separate division, as already shown. Three thoroughly equipped draw-kilns are connected with the Hartshorn quarries, being located upon the bay, adjacent to the latter. The market for this lime is found quite largely around the northern lakes, where it is highly esteemed.

The McFall Brothers burn lime of precisely the same sort as that previously described, in their two kilns which are located in Sandusky.

This large and important production has now been briefly reviewed. From this center, it will be borne in mind, a half million barrels of lime found market in 1887. It has been generally found possible to maintain a small difference in price between the Sandusky lime and the magnesian lime of the Genoa type, on account of the greater strength of the former. During 1887, however, the lime burned by natural gas in northern Ohio was crowding the magnesian limes in market and depressing the price of all; sharp competition was at the same time introduced into the sales of the lime production of Marblehead and Kelley's Island. The average price of the latter was probably below fifty-five cents during this year. With the average cost of wood at $2.35 per cord, and with the cost of barrels ranging between fifteen and twenty cents, it is obvious that the margin of profit was cut down

to the narrowest proportions, if indeed there was any margin left. It will probably be found that the united capacity of the lime-kilns of northern Ohio has grown beyond the present demands of the markets. The number of kilns in the Sandusky field has been trebled within the last five years.

The quality of lime burned here will always be in demand, and the manufacture is sure to be maintained, but it is quite likely that modifications will be introduced in the way of the fuel used, which will require a recast of the business.

The vexed questions as to the relative values of Sandusky and Genoa limes, to which reference has before been made, still await a settlement. The testimony of contractors, masons and bricklayers, as to the character of either, is of comparatively little value unless it is based upon a knowledge of both. Practical men of this class are generally satisfied with the behavior of the lime that they use, and are loth to admit that any change can be made without detracting from its value.

Few parts of the country are better supplied with limes of the highest excellence in both divisions than northern Ohio.

4. The Lime-Production of Central Ohio.

(a) *Franklin and Delaware Counties.*

Lime—Calcareous division.
Horizon—Upper Helderberg.

A lime-production of considerable importance has long been maintained at Columbus, and in its vicinity. The Scioto River occupies a rocky valley in the Upper Helderberg limestone from Columbus northward, throughout the county and beyond. Along this line there are numberless exposures of the limestone in cliffs, twenty to thirty feet in height. Many quarries have been opened in these exposures, some of which, as the State quarries and the Price quarries, have been worked on a very large scale. While the production of building stone has always been the main interest of the quarries, the production of lime has been an important subsidiary interest. All of the lime used in Columbus, until within the last three years, has been furnished from these sources.

To show its relations to the building stone, a brief statement as to the composition of the series in this part of the state will be required. The maximum interval between the Ohio shale (black shale) and the Lower Helderberg limestone in central Ohio is found to be about ninety feet. It is filled as follows:

Olentangy shale, Hamilton shale.....15 feet.

Delaware bluestone, Equivalent of { Sandusky bluestone, Flinty courses at Columbus, { Hamilton limestone, Marcellus shale, Upper Helderberg, } } 32 feet.

Bone bed..... 2 feet.

Columbus quarries, (Upper Helderberg limestone) { Columbus limestone, maximum, 18 ft Columbus building stone, maximum..... 25 ft } ..... 41 feet.

The division named above as the Columbus limestone is, with but little doubt, the exact equivalent of the Marblehead cap-rock, while the building stone below it is a more impure form of the Marblehead bottom-rock.

The lime and furnace-flux production of the Columbus quarries is, or should be, limited to the upper beds above indicated. The composition of this division has been made known by scores of analyses, made especially for the furnace interests of the Hocking Valley. The facts are also shown in analyses made for the Survey.

In Lilley's quarry, adjoining the old State quarries, there are fourteen feet of this upper limestone. It is divided into two sections by a bed that is known as the "smooth-rock." From this bed upwards there are eight feet, and below it, to the so-called "rough rock", there are six feet. The composition of these divisions is shown in the following table:

1. Upper division, 8 feet, Lilley's quarry. (*Lord.*)
2. Lower division, 6 feet, Lilley's quarry. (*Lord.*)

	1	2
Carbonate of lime	89.60	90.77
Carbonate of magnesia	4.41	3.26
Alumina and oxide of iron	.09	.46
Silicious matter	4.90	4.95
	100.00	99.44

The same series of beds that is represented in No. 2, of the above table is also covered by the following analysis (No. 1), from another quarry, made by Professor C. L. Mees, formerly assistant chemist on the Ohio Geological Survey, while still lower beds, including the building stone courses, are represented in No. 2. In No. 3 we have the composition of the purest and best sample that could be obtained:

1. From smooth rock downwards, 6 feet, in Smith & Price's quarry.
2. From building stone courses, still lower.
3. Selected sample of rock, from same quarry.

	1	2	3
Carbonate of lime	93.28	81.14	94.80
Carbonate of magnesia	2.69	16.00	1.21
Alumina and oxide of iron	2.18	1.08	.80
Silicious matter	1.41	1.94	3.20
	99.56	100.16	100.01

Further analyses of this limestone can be found on page 682, of the present volume.

The characteristics of the Columbus lime comes out to view in these figures. The stone from which it is burned contains about ninety per cent. of carbonate of lime, and is, consequently, a strong and hot lime, but the percentage of silica is a little higher than is desirable. The silica occurs in association with the fossils that constitute so large a part of the limestone.

The production has not been increased during the last ten years. There are but two draw-kilns used in the manufacture, and these are located in the city of Columbus, while a considerable part of the production is, as it always has been, derived from pot kilns of primitive construction, located near the various quarries. The truth is, the Columbus lime is being displaced, to quite an extent, from the field it has always hitherto occupied. Many of the bricklayers and plasterers of the city are abandoning the home supply in favor of the mild magnesian limes of Cedarville, Carey, Fostoria, Rising Sun, and other like centers of production. The Carey lime is especially valued for the finishing coat of the plasterers, on account of its extreme whiteness. Marion lime is also coming into the city in considerable amount.

For paper mill use and for gas purification, the Columbus lime ranks deservedly high.

The lime-production of Delaware county is less important than that of Franklin county, but it is of very much the same character. The same section of the Upper Helderberg limestones is the basis of the manufacture, and the process is conducted only upon a small scale, and, for the most part, in a primitive way.

At Delhi, in the valley of the Scioto, Meredith & Jones have two

draw-kilns, and John Jones one kiln. A good deal of their production is marketed by wagon, but they also reach the general markets by hauling to Radnor on the Toledo road.

Thomas Owens has a single draw-kiln, located a little lower in the valley than the Delhi kilns. Local demand covers much of his production.

(*b*) *Marion County.*

Lime—Calcareous division.
Horizon—Upper Helderberg.

Within the last ten years important centers of lime-production have been developed at two points in Marion county, on the line of the Columbus, Hocking Valley & Toledo Railroad, viz., at Marion and at Owen's Station.

Three or more interests have been combined in the development of these quarries, viz., the production of a superior building stone for the Columbus market, the supply of limestone in large quantity for flux for the Hocking Valley furnaces, and the manufacture of lime for the general market. To these interests has been added the supplying of crushed stone for road metal, in large quantity.

To meet these several demands the work of quarrying has been actively pushed, and a large amount of stone has been taken out. Limeburning, on a large scale, has been made the most prominent of the interests already named.

Marion.

One mile north of the Bee-line crossing, on the Columbus, Hocking Valley and Toledo Railroad, a short ridge or knob of Upper Helderberg limestone rises to the surface from under the heavy beds of drift that generally cover the country. It is separated by comparatively long intervals from any similar outcrop. It occupies a few acres only in extent; the highest portion is about twenty-five feet above the prevailing level of the country. The beds composing it are dipping to the east or northeast at an angle of two to five degrees, so that on the eastern extremity of the outcrop, which is also the highest portion, there is a much greater thickness of beds than is to be found at the western extremity. The quarries, as now developed, extend in an east and west line not more than twenty rods.

By means of this dip, combined with the deep excavations that have been made in two of the quarries, all the elements that enter into the Upper Helderberg limestone in northern and central Ohio are dis-

closed within this small area. The bottom of the series is reached in the drainage sump of the Norris & Christian quarry on the west, and, in a like situation, in the limestone quarry of John Evans on the north. Here there are found four feet of flinty courses, overlying by a short interval the Waterlime or Lower Helderberg limestone. The order of the beds seems very similar to that of the bottom of the series at Point Marblehead. Counting upward from this Lower Helderberg boundary, the first division that we find is the "*bottom-rock*" of the formation in northern Ohio. Its thickness here is twenty-five feet. In composition it consists of sixty-five to seventy per cent. of carbonate of lime, and twenty-five to thirty-three per cent. of carbonate of magnesia.

Next above it is the "*cap-rock*" of northern Ohio. It has a thickness of fifteen to twenty feet. It consists, on an average, of eighty-four per cent. of carbonate of lime, the several courses ranging from seventy-two to ninety-two per cent. It is the only part of the quarry that is used for furnace flux.

The Sandusky or Delaware blue stone completes the section, adding about thirty feet thereto. This is found in the easterly quarry, formerly owned by Smith & Sons but now by John Evans, and also in one of the original quarries of the latter party.

The series can be represented in tabular view as follows, viz.:

3.	Blue stone of Sandusky and Delaware, Hamilton limestone, Marcellus shale, &c., Used for building stone and road metal,	30 feet.
2.	Cap-rock or furnace-flux, Averages 84 per cent. of carbonate of lime,	20 feet.
1.	Bottom-rock, or limestone, Only rock used in kilns, Averages 66 per cent. of carbonate of lime,	25 feet.

Flinty courses, overlying at short remove the Lower Helderberg, 4 to 10 feet.

In this series there are four large quarries now opened—one on the west side of the railroad, owned and operated by Norris & Christian, and three on the east side, all owned and operated by John Evans.

The quarry on the west side embraces in its present workings only the lowermost division, or No. 1 of the column above represented. As it approaches the railroad, the section is re-enforced by the second division, or the furnace-flux; but this part of the property has not yet been developed.

In the Evans quarries the entire series is included. The northernmost workings are in division No. 1. The middle quarry includes fifteen feet of the blue stone (No. 3), and also about the same amount of the second division, or furnace-flux. The easternmost quarry is operated altogether in No. 3, or the blue stone.

The latter element is a valuable one in the quarry interest. It yields a handsome, even-bedded and exceedingly strong stone, excellently adapted to range work. It is highly esteemed and largely used in Columbus, and in the other markets which it reaches. The spalls are all turned to good account for road metal and railroad ballast, several crushers being kept at work in preparing them for these lines of service.

Lime-Production.

Norris & Christian have thus far but a single interest in operating their quarry, viz., the production of lime. Their present workings cover the entire thickness of the lowermost division. The quarry-face is about twenty feet in the longest sections now exposed. The quarry equipment is efficient in every respect, steam being used in lifting the stone and in pumping. They have five excellently-planned and thoroughly-built draw-kilns in operation, and are about adding a sixth. The daily production of their several kilns ranges from 250 to 280 bushels. Most of their lime is sold in bulk, but they are also prepared to ship in barrels. The production of these five kilns in 1887 was 320,000 bushels of seventy pounds weight. The best of wood for burning the lime is secured by wagon and rail at $2.00 per cord.

The composition of the limestone, as determined from a careful sampling of all the courses of the quarry, is as follows:

Marion Limestone, from Norris & Christian's quarry. (*Lord.*)

Carbonate of lime	66.02
Carbonate of magnesia	33.10
Alumina and oxide of iron	.24
Silicious matter	1.60
	100.96

The lime has an excellent and growing reputation. It has found market in Cleveland, Cincinnati and Columbus, and at many other points, everywhere displacing limes that have been used for a long time and acceptably. One of its principal uses is in paper mills and strawboard works. For plastering and brick work, also, it seems to be well-approved. It lacks the extreme whiteness of the dolomites of northern Ohio, but still it compares well in this respect with ordinary white limes.

Its durability in mortar seems to be all that could be asked. It appears to much better advantage in walls that have been exposed for a score or more of years than Columbus lime, for example, and will apparently compare favorably in this regard with the dolomitic limes.

Mr. Evans has five draw-kilns connected with his limestone quarry. The capacity of the kilns is about 240 bushels daily. To keep up this production, a consumption of three cords of wood of the best quality is required. All the lime of this plant is sold in bulk. It is identical in character with the lime already described, and is applied to the same uses. The section of the limestone quarry of Mr. Evans coincides exactly with the section of the Norris & Christian quarry. Both begin and end alike.

Mr. Evans has the limestone of the second division opened on a large scale, as a source of flux for the Hocking Valley furnaces. He has sometimes filled his kilns for a few days with the stone of this division, but he reports unfailing dissatisfaction on the part of his customers with the lime derived from this source. Complaint is made of its being fiery and unmanageable. The lime in question, it will be remembered, contains eighty-four per cent. or more of carbonate of lime.

Owens' Station.

The remaining lime-production of this district is found at Owens' Station, five miles south of Marion.

A considerable area of limestone either comes to the surface in this region or is covered with but a thin covering of drift. The quarries have been worked for twenty-five years for lime and building stone, but in the large way only since the Toledo railroad has been opened. They are now owned and operated by Daniel Owens & Son. Four or five acres have been worked already as deep as it seems practicable to carry them.

Three draw-kilns are established here, the daily capacity of which is rated at 200 bushels. Mr. Owens reports a consumption of about four cords of wood to a kiln. The cost of wood ranges from $1.50 to $1.75, sometimes reaching $2.00. The production of the kilns in 1887 was about 175,000 bushels (seventy pounds to the bushel).

The character of the lime is quite different from that of the Marion lime, as will be seen from the account here appended of the range of the quarries.

The stone reached in these quarries includes the lower half of No. 3 (the blue stone division) of Marion, and the whole of the middle division, or No. 2, of the section given on a preceding page, together with a few feet of the lowermost division, or No. 3. It can be shown thus, in diagram:

Section of Owens' quarry—

Blue stone, Sandusky or Delaware, lower half	15 feet.
Flux-stone, or cap-stone	20 feet.
Bottom-rock, or limestone	5 feet.
	40 feet.

A heavy easterly dip brings in the blue stone on the surface of the quarry upon the east side. This division is worked for building stone and road-making material, the only purposes to which it is adapted. The remaining courses, which are devoted to limestone and furnace-flux, may be roughly classed as follows—in fact, the quarry is worked in sheets about as here indicated:

8. Beds aggregating 3 feet.
7. Beds aggregating 3 feet.
6. Beds aggregating 3 feet.
5. Beds aggregating 2½ feet.
4. Beds aggregating 4 feet.
3. Beds aggregating 4 feet.
2. Beds aggregating 3½ feet.
1. Beds aggregating 2½ feet.

The line of division between the cap-rock and bottom-rock probably passes between Nos. 2 and 3 of the above table.

Through the courtesy of Mr. Owens, the following analyses of these several divisions have been furnished. They were made by Professor Lord for the Columbus and Hocking Coal and Iron Company, as a guide in the selection of furnace flux. The numbers above given are used in the table:

	8	7	6	5	4	3	2	1
Carbonate of lime.....	88.30	80.40	84.70	92.00	85 55	74.00	66.15	72.85
Carbonate of magnesia.....	2.58	13.80	8.64	.56	10.39	21.46	27.97	22.38
Alumina and oxide of iron..	4.00	1.25	4.33	6.01	3.05	1.85	1.97	2.65
Silicious matter.....	3.20	4.60	2.92	1.35	1.57	1.92	2.20	1.65
	98.08	100.05	100.66	99.92	100.56	99.23	98.29	99.53

This table tells its own story with great distinctness. Nos. 3 to 8, inclusive, belong to the flux-stone of the Marion section. Nos. 1 and 2 probably belong to the limestone, or lower division, of the quarries above named. If Mr. Owens chooses to go lower in his present workings, he will reach the same stratum that is supplying the Marion kilns. The stone is commonly worked in the sheets as they are numbered above, and, consequently, any quality of lime indicated in the table can be procured to order.

The lime now produced is, for the most part, a fiery lime, excellently adapted to paper and straw-board factories, and also to gas purification and glass making. For mason's and plasterer's use it is also reported as popular, but judging by the experience of other producers, it is likely to be displaced when brought into direct competition with milder limes. Such, at least, has been the usual experience in the state.

The lime found market last year as far east as Greenville, Pennsylvania, and as far west as Muncie, Indiana. The prevailing price for the year was nine cents per bushel, or fifty cents per barrel, when ordered in car-load lots.

The lime produced in the kilns of Marion and Owens' Station for 1887 aggregates about 250,000 bushels of seventy pounds, or 87,500 barrels of 200 pounds to the barrel.

SUMMARY.

In bringing to a close this review of the limes of Ohio, the following summary will be found serviceable.

There are, as shown in the preceding pages, four leading grades of lime now used in the large way in the state, if the term grades can with propriety be used in designating proportions of lime and magnesia that are fairly constant. They are as follows:

1. Limes derived from stone containing eighty-five to ninety-five per cent. of carbonate of lime.
2. Limes derived from stone containing seventy-five to eighty-five per cent. of carbonate of lime and about twenty per cent. of carbonate of magnesia.
3. Limes derived from stone containing sixty-five to seventy-five per cent. of carbonate of lime and twenty-five to thirty per cent. of carbonate of magnesia.
4. Limes derived from stone containing, approximately, fifty-five per cent. of carbonate of lime and forty-four per cent. of carbonate of magnesia (dolomites).

1. Under the first head are to be counted the Clinton limes of Clarke and Miami counties, the Columbus lime, the Ohlemacher lime of Sandusky, and the Owens' Station lime of Marion county.

2. Under the second head are counted the limes of Point Marblehead and Kelley's Island (Sandusky lime), with the exception of Ohlemacher's lime.

3. Under the third head are counted the limes of New Paris, Preble county, and of Marion.

4. Under the fourth head are counted the magnesian limes of southwestern Ohio, and also of northern Ohio, which are well represented in the limes of Springfield, Cedarville, Genoa and Fremont.

Ths stone of the first division does not appear to be burned by preference, except in the case of the Clinton limes. In the other instances, it is the only stone available in the particular quarries that are worked.

The stones of the second and third divisions are, however, selected for this purpose in the presence of stone of the first division (with the exception of New Paris). It is so much preferred, in fact, that great expense is incurred in removing the stone of the first division in order to reach this particular grade.

The production of the fourth division largely exceeds that of all the other divisions united. The second and third divisions are being expanded rapidly. The first division has but two active centers, viz., the kilns of Ohlemacher & Company and of Owens & Son.

The conclusion is obvious, that with all the the grades of limestone above indicated open to their use, the markets of Ohio and adjacent territory, decidedly prefer for sources of mortar-limes, stones that contain from twenty to forty-five per cent. of carbonate of magnesia. This selection has been made, it is needless to remark, solely on practical grounds, the true chemical relations of these several sources of lime never having been before made known.

CHAPTER XVI.

THE DRIFT DEPOSITS OF OHIO.

By Edward Orton.

The title of this chapter may prove misleading. No discussion of the origin or of the order of arrangement of the several kinds of drift deposits found in the state is to be attempted here. The main object is to furnish in tabular form, and with due reference to geographical location and continuity, the facts that have been published in the foregoing pages, showing the thickness of the drift in the state, and particularly in its western half. To the figures already given a few others will be added.

The facts referred to in the preceding statement have all been obtained during the recent search for oil and gas that has been going forward in Ohio. The present chapter thus makes a sort of supplement to the chapters that treat specifically of this search. It will be proper, in the same connection, to gather up the various facts connected with the occurrence of gas or oil in drift-beds throughout the state. Many such facts have been already reported in earlier chapters of the present volume.

The Drift as a Source of Gas.

On the southern margin of the drift in Ohio, and for thirty or forty miles back from this margin, there are in many parts of the state considerable accumulations of vegetable matter in the shape of buried tree-trunks, branches, leaves and fruits. These accumulations are often fairly continuous over considerable areas, constituting, in such cases, the "forest bed" of Newberry. They are sometimes included in masses of true bowlder clay, but more generally are found upon the surface of the bowlder clay, and are then covered only by the later deposits of the drift period, as sands, gravels and stratified clays. When found in-

cluded in the bowlder clay, the vegetation must have been derived from pre-glacial growths, by which the surface of the country was covered before it was overrun by the ice. When resting on the bowlder clay, a different origin is often clearly to be made out. The vegetation is in many of the latter cases indigenous or native to the spot where it is found. Trees are found in the drift with their roots extending into the bowlder clay, and with leaves, and even fruits, well preserved in the clays and sands that cover them.

The depth at which these vegetable remains occur varies between wide limits. A score or two of feet are often found, a hundred feet more rarely, and in a single case, four hundred feet of cover were reported for a considerable amount of wood.

The wood is sometimes found in a fair state of preservation, but it is generally well along in decomposition. When brought into the air the largest fragments of tree trunks will, as a rule, rapidly disintegrate, the layers of annual growth separating easily. The kind of wood represented in these accumulations is, in almost all cases, red cedar. The leaves and berries of this same tree are sometimes found associated with the wood. Its dark color leads to a popular identification of it as black walnut.

This vegetable material is, in most if not in all instances, undergoing a slow decomposition, giving rise thereby to the ordinary products of decay under such circumstances, viz., carbonic acid and light-carburetted hydrogen or marsh gas. Wells that are dug through or to these deposits often strike considerable accumulations of one or other of these gases. It sometimes happens that the former (carbonic acid gas or choke damp) is found in all the wells of a neighborhood. There is a small district near Mt. Sterling, in Madison county, in which no water well (unless a driven well) has ever been completed, on account of the large amount of this gas encountered in the descent and before a water-bearing bed was reached. Several well-diggers have lost their lives in the attempt to pass through this poisonous zone. (Geology of Ohio, Vol. III, p. 428.)

Much more frequently, however, marsh gas is struck in these vegetable deposits, sometimes escaping in large volume and with great force when first released, and sometimes giving rise to a small but persistent supply. The examples of such gas production are of common occurrence in all the area already pointed out.

No examples are known in the state of the utilization of the gas that is thus produced. In Champaign county, Illinois, gas that apparently originates under precisely similar conditions has been introduced into farm-houses for heat and, after being enriched by a gasoline bath,

for light also. Such supplies, amounting to a few hundred feet per day, have been maintained for many years.

It is scarcely to be doubted that supplies of this character are available in some parts of Ohio. In fact, the amounts that certain wells are known to have produced would be equal to the demands that would be made upon them in household use.

It is well to bear in mind that the conditions for the production of gas supplies of this sort are wide spread and in constant operation. To find inflammable gas in small or moderate quantity in the drift is not a ground of surprise. It is an everyday and common-place occurrence.

It is also to be remembered that the discovery of such supplies gives no true indication whatever of the presence of rock gas in the underlying strata. Cases will presently be named in which gas in the drift may be referred to the underlying rocks, but so far as supplies that are known to be connected in origin with the great bodies of buried wood that the drift formations contain, no warrant is given by them to expect any gas whatever from the rocky series on which these drift-beds rest. This drift gas originates at a greater or less remove from the rocks, and generally has no connection with them.

In the subsequent section there will be discussed another sort of drift gas.

The Drift as a Reservior of Gas and Oil.

Under this head certain accumulations of oil and gas that are occasionally found in the drift will be described. At first sight all of these occurrences of gas might seem alike, but a little examination suffices to show a broad line of distinction between them. In the case now considered, porous beds of drift directly overlie gas-bearing or oil-bearing rocks, and during the long periods in which they have maintained this relation they have, when suitable conditions of level have been found, been charged with gas or oil.

The Mecca oil-field gives an example of this sort of accumulation. As stated on page 330, the bowlder clay overlying the Berea grit at this point has become saturated with oil. Another case of the occurrence of oil from the bowlder clay has recently been reported from southern Ohio. Cases of oil accumulation are, however, comparatively rare. It is of somewhat more frequent occurrence that beds of gravel resting on the Ohio shale, or other gas-producing stratum, become charged with high-pressure gas. The most interesting cases that have been noted under this head are recorded on page 349. At Wellington, Lorain county, at a depth of forty feet from the surface, the interval being filled with bowlder clay, a bed of sand and gravel was found, heavily charged with

gas, which is obviously derived from the Black Berea shale on which the porous beds rest. The gas, when its reservoir was tapped, escaped with great violence.

Hon. R. A. Horr, whose residence is near this well, was encouraged by this experience to drive a pipe on his own premises to the sand bed. He was rewarded by a flow of gas which has supplied his house with heat and light for the last six months, and which shows thus far no perceptible abatement.

A similar case is reported from Cleveland on page 430. It will also be remembered that the drift beds at Findlay were directly connected with the surface indications that the people there so long and persistently refused to recognize in their true significance. In penetrating them gas was almost always obtained in considerable abundance.

The two distinct sources of gas in the drift have now been pointed out, and, in view of the facts already presented, its frequent occurrence is seen to be no ground of surprise. Its geological significance is also easily apprehended. As a rule, it has no bearing on the question of rock supplies.

The Thickness of the Drift Deposits in Ohio.

Under the last section will be included the facts pertaining to the thickness of the drift beds in Ohio, for the statement and arrangement of which this chapter is mainly written. Five years ago the suggestion that we could ever obtain as much knowledge in regard to the thickness and character of the deposits under which the rock floor of the western half of Ohio is buried as we now have in hand, would have seemed visionary and extravagant to a high degree. Such an opportunity comes but once in the history of a district or a state. It is fortunate that we have been able to secure so large a representation of the results that have been obtained.

The figures that the drillers' records have yielded are probably in excess of all the estimates that have hitherto been made. Data are now, for the first time, furnished from which a reasonable calculation can be made as to the total amount of drift which has been deposited over parts of western Ohio. For other sections of the state there are not even yet facts enough to render such calculations safe.

There are a number of counties in the northern part of the state in which the rock lies, in the main, quite shallow. Erie, Ottawa, Sandusky, Seneca, Wood and Hancock belong in this list, or in other words, the counties constituting the southwest boundary of Lake Erie. The deepest deposits prevail in the two western tiers of counties as far south

as Dayton. Another series of heavy deposits extends through several of the central counties.

The thickest deposit yet found is at St. Paris, Champaign county. The drive pipe descended there to the extraordinary depth of 530 feet without reaching bedded rock. An account of this remarkable section is found on pages 276–7. At 400 feet a considerable amount of vegetable materials, including fragments of wood and bark, was encountered. An ancient and important drainage channel of pre-glacial Ohio is obviously located, so far as a single point can serve, by this section. The continuation of this channel to the southward is probably indicated in the wide erosion of the cliff limestone on the western side of Clarke county. This valley was pointed out in Vol. I, Geology of Ohio, as the probable location of the Great Miami River in an earlier day (Map—Chap. XIII). To the northwest of Champaign county, through Auglaize and Mercer counties, great erosion in the bedded rocks has been experienced, the entire sheet of cliff limestone being removed in several instances, as shown by the well records. It is obvious that there are possibilities of broad and deep continuous water-ways throughout this region.

In the table that follows, the thickness of the varied sheets of drift that cover the western and, to some extent, the central portions of the state is given. The record is made up by counties, and the enumeration is begun in the northwestern corner of the state. The counties are followed from west to east through the several tiers.

The records of a few wells in Indiana, adjacent to northwestern Ohio, will also be given in this list. They are as follows:

	Thickness of Drift.
Auburn, Indiana	282 feet.
Kendallville, Indiana	400 feet.
Butler, Indiana	378 feet.
Fayette, Indiana	200 feet.
Blissfield, Michigan	200 feet.

(*Williams, Fulton, Lucas.*)

Williams County.	
Bryan, Well No. 1	154 feet.
Bryan, Well No. 2	146 feet.
Bryan, Well No. 3	176 feet.
Bryan, Well No. 4	157 feet.
Fulton County.	
Wauseon, Well No. 1	156 feet.
Delta, Well No. 1	115 feet.
Lucas County.	
Monclova	18 feet.
Toledo, Rolling Mill Well No. 1	110 feet.
Toledo, Air Line Junction Well	120 feet.
Waterville	20 feet.
Waterville, Well No. 1	20 feet.

(Defiance, Henry, Wood, Ottawa, Sandusky.)

DEFIANCE COUNTY.

	Thickness of Drift.
Defiance, Well No. 1, Valley of Maumee	18 feet.
Hicksville, Well No. 1	128 feet.

HENRY COUNTY.

Napoleon, Well No. 1	48 feet.
Deshler, Well No. 1	71 feet.

WOOD COUNTY.

Bowling Green	Rock at surface.
Portage	Rock at surface.
North Baltimore, Well No. 1	43 feet.
North Baltimore, Peters' Well, No. 1	16 feet.
Rocky Ford, Well No. 1	61 feet.
Bairdstown, Simon's Well	Rock at surface.
Bloomdale, Well No. 1	16 feet.
Bradner, Well No. 1	20 feet.
Weston, Well No. 1	70 feet.

OTTAWA COUNTY.

Port Clinton, Well No. 1	48 feet.
Oak Harbor, Well No. 1	39 feet.
Elmore, Well No. 1	42 feet.
La Carne, Well No. 1	100 feet.

SANDUSKY COUNTY.

Fremont, Well No. 1	10 feet.
Clyde, Well No. 1	130 feet.
Clyde, Well No. 2	57 feet.

(Putnam, Hancock, Seneca, Huron.)

PUTNAM COUNTY.

Ottawa, Beckmann Well	95 feet.
Ottawa, Citizens' Well	50 feet.
Columbus Grove	17 feet.
Leipsic	78 feet.
Kalida	15 feet.

HANCOCK COUNTY.

Findlay, Pioneer Well	8 feet.
Findlay, Jones Well	8 feet.
Findlay, Karg Well	18 feet.
Findlay, Cory Well	36 feet.
Arcadia, Well No. 1	55 feet.
McComb, Well No. 1	62 feet.

SENECA COUNTY.

Tiffin, Well No. 1	Rock at surface.
Liberty Township, Frost Well	45 feet;
Green Springs, Well No. 1	17 feet.

HURON COUNTY.

	Thickness of Drift.
Norwalk, Deep Well No. 1	85 feet.
Bellevue, Well No. 1	17 feet.
Plymouth, Well No. 1	12 feet.
Chicago Junction, Well No. 1	120 feet.
New London, Well No. 1	90 feet.

(Wyandot and Crawford.)

WYANDOT COUNTY.

Upper Sandusky, Well No. 1	20 feet.
Upper Sandusky, Well No. 2 (Taylor)	70 feet.
Upper Sandusky, Well No. 3 (Steby)	70 feet.
Upper Sandusky, Well No. 4 (Infirmary)	40 feet.
Upper Sandusky, Well No. 5 (McConnell)	68 feet.
Carey, Well No. 1	Rock at surface.
Whartonsburg, Well No. 1	48 feet.

NOTE.—Nos. 1 and 4 are located in valleys. The prevailing thickness of drift in the central portion of the county appears to be 70 feet.

CRAWFORD COUNTY.

Bucyrus, Well No. 1	20 feet.
Bucyrus, Well No. 2	30 feet.
Crestline, Well No. 2	27 feet.

(Van Wert, Allen, Hardin, Marion.)

VAN WERT COUNTY.

Van Wert, Well No. 1	32 feet.
Delphos, Well No. 1	5 feet.

ALLEN COUNTY.

Lima, Well No. 1	18 feet.
Bluffton, Well No. 1	5 feet.

HARDIN COUNTY.

Kenton, Well No. 1	24 feet.
Patterson, McVitty Well	4 feet.
Forest, Well No. 1	69 feet.

MARION COUNTY.

Marion, Well No. 1	18 feet.
Prospect, Well No 1	54 feet.

(Mercer, Auglaize, Shelby, Logan, Union, Delaware.)

MERCER COUNTY.

Celina, Well No. 1	70 feet.
Franklin Township, Doenzes Well	110 feet.
St. Henry, Well No. 1	187 feet.
St. Henry, Well No. 2	134 feet.
Ft. Recovery, Well No. 1	145 feet.
Mendon, 3 miles east of	25 feet.
North line of county	15 to 50 feet.
South edge of Reservoir	40 to 100 feet.

AUGLAIZE COUNTY.

	Thickness of Drift.
Wapakoneta, Well No. 1	96 feet.
Wapakoneta, Well No. 2	153 feet.
Buckland, 2½ miles west	40 feet.
North line of County	15 to 50 feet.
Minster, 2 miles northwest of	220 feet.
New Bremen	110 feet.

Cridersville and Vicinity.

Cridersville, Well No. 1, Cobb, Page & Co	300 feet.
Duchouquet Township, Sec. 34, Lydia DeLong Well	335 feet.
Duchouquet Township, Sec. 34, H. Beeler Well	170 feet.
Duchouquet Township, Sec. 3, Geo. DeLong Well	428 feet.

St. Mary's and Vicinity.

St. Mary's, 2 miles south of	375 feet.
St. Mary's, Well No. 1	121 feet.
St. Mary's, Well No. 2	110 feet.
St. Mary's, Giddens Well	220 feet.
St. Mary's, Koop Well, No. 1	320 feet.
St. Mary's Township, Sec. 30, Wm. Axe Well	80 feet.
St. Mary's Township, Sec. 22, Kellermyer Well	92 feet.
St. Mary's Township, Sec. 22, Quellhorst Well	90 feet.
St. Mary's Township, Sec. 14, Kirtin Well	120 feet.
St. Mary's Township, Sec. 15, J. R. Wilkins Well	90 feet.
St. Mary's Township, Sec. 15, Miller Well	100 feet.
St. Mary's Township, Sec. 15, Longswirth Well	40 feet.
St. Mary's Township, Sec. 15, C. Wilkins Well	60 feet.
St. Mary's Township, Barrington Well	30 feet.
St. Mary's Township, Armstrong Well	125 feet.
St. Mary's Township, Young Well	24 feet.
Washington Township, Sec. 19, W. Schroyer well	400 feet.

SHELBY COUNTY.

Sidney, Well No. 1	Rock shallow.
Sidney, Well No. 2	" "
Sidney, Well No. 3	90 feet.
New Berlin	428 feet.

LOGAN COUNTY.

Bellefontaine, Well No. 1	150 feet.
Belle Center, Well No. 1	40 feet.
Huntsville, Well No. 1	67 feet.

UNION COUNTY.

Marysville, Well No. 1	196 feet.
Magnetic Springs, Murphy Well	40 feet.

DELAWARE COUNTY.

Delaware, Well No. 1	20 feet.

(*Darke, Miami, Champaign, Clarke, Madison, Franklin, Licking.*)

DARKE COUNTY.

	Thickness of Drift.
Greenville, Well No. 1	89 feet.
Union City, Well No. 1	104 feet.

MIAMI COUNTY.

Troy, Well No. 1	133 feet.
Piqua, Well No. 1	Rock at surface.
Covington, Well No. 1	Rock at surface.

CHAMPAIGN COUNTY.

Urbana, Well No. 1	155 feet.
Urbana, Well No. 2	133 feet.
Urbana, Well No. 3	102 feet.
St. Paris, Well No. 1	530 feet.
St. Paris, Well No. 2	370 feet.
Mechanicsburg, Well No. 1	280 feet.

CLARKE COUNTY.

Springfield, Well No. 1	Rock at surface.
Pike Township, Mower Well	93 feet.

MADISON COUNTY.

London, Well No. 1	155 feet.
London, Well No. 2	250 feet.

FRANKLIN COUNTY.

Columbus, State House Well	123 feet.
Columbus, Natural Gas Company's Well	104 feet.

LICKING COUNTY.

Newark, Well No. 1	235 feet.
Newark, Everett Well	165 feet.

(*Preble, Montgomery, Greene, Fayette, Pickaway, Fairfield*).

PREBLE COUNTY.

Eaton	Rock shallow.
Camden, Well No. 1	181 feet.

MONTGOMERY COUNTY.

Dayton, Well corner First and Findlay streets	247 feet.
Miamisburg, Well No. 2	181 feet.

GREENE COUNTY.

Xenia, Well No. 1	94 feet.
Osborn, Well No. 1	207 feet.

FAYETTE COUNTY.

Washington C. H., Well No. 1	70 feet.

PICKAWAY COUNTY.

Circleville, Well No. 1	140 feet.

FAIRFIELD COUNTY.

	Thickness of Drift.
Lancaster, Well No. 1	132 feet.
Lancaster, Mt. Pleasant Well	60 feet.
Hadley Junction, Well No. 1	335 feet.
Carroll, Well No. 1	260 feet.

(*Butler, Hamilton, Warren, Clinton.*)

BUTLER COUNTY.

Hamilton, Well No. 1	200 feet.
Hamilton, Well No. 2	214 feet.
Oxford, Well No. 1	40 feet.
Middletown, Well No. 1	10 feet.

HAMILTON COUNTY.

Cincinnati, Well corner George and Freeman	48 feet.
Cincinnati (Newport), Hemingray Well	70 feet.
Cincinnati, Gas Company's Well	120 feet.

WARREN COUNTY.

Lebanon, Turtle Creek Well	126 feet.

CLINTON COUNTY.

Wilmington, Well No. 1	84 feet.

A few figures in the same line are given from counties outside of the limits that have been considered:

Richland County	Shelby	58 feet.
Knox County	Mt. Vernon	97 feet.
Summit County	Coventry	27 feet.
Summit County	Akron	50 feet.
Medina County	Medina	35 feet.
Lorain County	Wellington, Well No. 1	108 feet.
Lorain County	Wellington, Well No. 2	85 feet.
Stark County	Massillon	145 feet.
Stark County	Canton	17 feet.
Wayne County	Wooster	28 feet.
Coshocton County	Coshocton	171 feet.
Hocking County	Logan	28 feet.
Hocking County	Logan	32 feet.
Trumbull County	Youngstown (Reywight Well)	84 feet.
Trumbull County	Youngstown (Hazelton Well)	60 feet.
Scioto County	Portsmouth	70 feet.
Guernsey County	Kimbolton	76 feet.
Guernsey County	Cambridge	54 feet.
Jefferson County	Steubenville	75 feet.

Many of these records are derived from drilling done in the valleys of central and southern Ohio, and thus serve to show the great amount of pre-glacial erosion that these regions have endured. A few examples are appended:

Mad River and Miami System.

	Thickness of Drift.
St. Paris	530 feet.
Urbana	155 feet.
Osborn	207 feet.
Troy	133 feet.
Dayton	247 feet.
Miamisburg	181 feet.
Camden	181 feet.
Hamilton	214 feet.
Lebanon	126 feet.
Cincinnati	120 feet.

Scioto Valley.

Columbus	104 feet.
Circleville	140 feet.

Hocking Valley.

Hadley Junction	335 feet.
Carroll	260 feet.
Lancaster	132 feet.

Muskingum Valley.

Newark	235 feet.

NOTE.—The list above given can be greatly increased in value if those who read this chapter will forward to the author any additional facts pertaining to this subject.

Low-water at Cincinnati is counted 440 feet above mean tide. By examination of the facts given above, in connection with the surface elevations of the locations of the wells, it is seen that this ancient erosion has been in several instances carried below the lowest point from which, at the present day, water can be drained, within the limits of the state. The deep excavations shown in the Dayton well and in the Hamilton well, as well as in the Cincinnati records, are examples of this sort. At these, and many other points, the erosion has reached several hundred feet below the present drainage levels of the districts within which these wells are included.

What is counted above as thickness of the drift is very likely to be in some cases a few feet in excess of the facts. The length of the drive pipe may have been given instead of the exact thickness of the drift beds. The drive pipe is generally carried a few feet into the underlying bedded rock.

CHAPTER XVII.

SUPPLEMENTAL REPORT ON THE NEW GAS FIELDS AND OIL FIELDS OF OHIO.

By Edward Orton.

In the brief chapter which is here to follow, a few of the latest facts in regard to gas and oil from the new horizons will be stated.

The Clinton Limestone.

Lancaster.

On pages 382–388 an account is given of the important discovery at Lancaster of a source of high-pressure gas in respectable volume in the Clinton limestone. The facts there presented have been supplemented in the interval that has passed since they were put in type. Two additional wells have been drilled since that date, the records of which are as follows:

Well No. 4 is located on the west side of town, at the brewery, about one-half mile south of No. 2. Gas was struck at a depth of 1950 feet, and the daily flow, as measured by Professor G. W. Welch, superintendent of schools, is 650,000 feet per day. This flow is from a 4¼-inch pipe.

Well No. 5 is one-half a mile south of No. 4. It was completed in February, 1888. It found gas at 1940 feet, and its daily production is 260,000 feet per day, from a 4¼-inch pipe.

On page 387 the prediction was made that a closed pressure far in advance of the Findlay field would be found in the Lancaster wells. This prediction is verified, at least in part, in the following table, viz.:

Closed or rock-pressure of Well No. 1.....355 pounds to square inch.
Closed or rock-pressure of Well No. 2.....285 pounds to square inch.
Closed or rock-pressure of Well No. 3..... 310 pounds to square inch.
Closed or rock-pressure of Well No. 4.....700 pounds to square inch.

The last figure, derived from the most recently completed well of the list, probably exhibits the normal rock pressure of the field.

The table of production of the five wells now completed is appended:

	Size of pipe.	Daily production.
Well No. 1	$5\frac{5}{8}$ inch.	74,880 cubic feet.
Well No. 2	$4\frac{1}{4}$ "	878,000 " "
Well No. 3	$5\frac{5}{8}$ "	792,000 " "
Well No. 4	$4\frac{1}{4}$ "	650,000 " "
Well No. 5	$4\frac{1}{4}$ "	260,000 " "

None of the wells have been torpedoed except No. 1, and the measurement of this, as above given, was taken before the shot.

Wells Nos. 2 and 3 are furthest north, and the inference from present developments is obvious that the best promise is to be found in that direction.

The cost of the wells has been greatly reduced since the facts of the section have come to be understood. The last two wells have cost only about $3,500 each. Well No. 4 was put down in thirty-seven days.

For the facts of the Lancaster field, including the measurements of the last two wells, the Survey is under great obligation to Superintendent G. W. Welch. It is to this gentleman as much, to say the least, as to any other that Lancaster owes her present good fortune in a natural gas supply. The town is rapidly being piped, and the introduction and use of the gas give great satisfaction.

The Trenton Limestone.

Tiffin.

A good deal of drilling has gone on in and around Tiffin during the last few months. The success of the Loomis and Nyman well, described on page 199, has revived the interest in the search, and two of the six wells since drilled have started out with a production of considerable value. The most recent testimony is, however, to the effect that this production is not well-sustained, oil having followed the gas very closely. This implies that the arches for gas accumulation are small. The record of the wells is summarized below:

Powell Well, one-eighth mile below Loomis and Nyman well, in river valley.
Trenton limestone reached at.....1455 feet.
Depth in Trenton..... 38 feet.
Production estimated at 1,250,000 cubic feet per day.

Foraker Well, near water works dam, in river.
Trenton limestone reached, about.....1550 feet.
or 100 feet lower than in Loomis & Nymam well.
Well unproductive.

Harshberger Well—Trenton limestone reached at.....1547 feet.
Drilled to depth of.....1753 feet.
Well unproductive.

King Well, one mile northeast of town.
Trenton limestone reached at .....1605 feet.
Drilled into Trenton .....120 feet.
Well unproductive.

Atkins Well, four miles west of town.
Trenton limestone reached at.....1484 feet.
Drilled to depth of.....1647 feet.
Well unproductive.

Eureka Well, two squares east of Loomis & Nyman well.
Trenton limestone reached at.....1467 feet.
Well torpedoed in November, 1887.
Production estimated at 2,000,000 cubic feet per day.

Welch well, located in town, south of Pennsylvania R. R. station.
Trenton limestone reached at.....1455 feet.
Depth in Trenton.....24 feet.
Production estimated at 400,000 cubic feet per day.

Fanning well, 600 feet north and a little west of Welch well.
Trenton limestone reached at.....1459 feet.
Depth in Trenton limestone.....22 feet.
Production estimated at 1,250,000 cubic feet per day.

In the last named well, which was finished in February, 1888, the gas-rock was found much looser in texture than in any well previously drilled. Its natural flow was also greater, but the increase by "shooting" was much less than had been gained in the other productive wells. It is free from oil as yet, but the days of its exemption are probably numbered. The wells, when shot, produce dry gas for about five weeks. At the end of that time, the oil appears with the gas and in the case of the wells whose production is largest, it gains rapidly at the expense of the gas, choking it out in a short time. The Powell well has already been overrun so as to be valueless for gas. The smaller well of Loomis and Nyman produces about two barrels of oil per day, without any decided loss of gas so far as noted. It was torpedoed with a small shot a few months since, and its flow is reported as increased thereby several fold. It is now said to carry the boiler connected with the works, ten large stoves, the melting pots for Babbit metal and brass, the core ovens and twenty or thirty torches for illumination. Its rock pressure is, however, rapidly declining. Before the well was torpedoed, the pressure was at least 650 pounds to the square inch (see page 200). At the present time it never rises above 325 pounds.

These facts serve to indicate the real nature of the Tiffin field. A well marked fold passes through the center of the town, but it is of

small extent. The gas which occupies the summit is in all cases closely followed by the oil, and the oil is, as usual, followed and impelled by salt water that gains its head of pressure from distant outcrops of the rock that contains it.

The estimates of the original production of the Powell and Eureka wells were doubtless large. It is not known that measurements were made at the time.

Bryan.

Bryan has continued the search for gas and oil in the Trenton limestone of its vicinity. The record on page 247 brought the history down to well No. 3. This well is one mile south of the court house. Well No. 4 was located 3,000 feet southwest of it.

The record of No. 4, in briefest terms, is as follows:

Drift.....157 feet.
Cased at.....1300 feet.
Trenton limestone.....1914 feet.
Gas at.....1958 feet and 1976 feet.
Well finished at 1980 feet, where a little oil appeared.

A few feet of red Medina shale were struck just below the casing. The well was shot with sixty quarts of nitro-glycerine. The effect was to increase the flow of gas and also of the oil which appeared in small quantity just below the lowest gas.

The well was measured December 10th, 1887, by the anemometer, and the daily yield was found to be 70,560 feet, at a temperature of about 32° F. A considerable increase of production has since been reported from this well.

A few additional facts in regard to well No. 3 will be given.

This well was also "shot" in December, 1887, with a moderate charge, but no advantage was realized from the operation. A column of water, 1,900 feet in depth, had been left upon the gas-rock for some time, from a leaky casing, and the force of the gas was greatly reduced thereby. In October, 1887, the pressure rose to 200 pounds in nine and one-half minutes. In December it rose to 67 pounds in the same time, and to 118 pounds in one hour

Measured by the anemometer, December 10th, 1887, the flow of gas was found to be 154,087 feet, at a temperature of about 32° F. The united capacity of these wells, measuring the entire flow at the well heads, is seen to be 224,647 feet per day, or in round numbers, a quarter of a million cubic feet. It has not yet been piped to the town for use. An expenditure of at least $25,000 has been made here and the results are given above.

At Edgerton, in the same county, a well has been drilled, the production of which is reported as 150,000 cubic feet per day. It is utilized to some extent in the village.

St. Henry's Gas Field.

The St. Henry's field, which was opened in December, 1886, has been developed and enlarged since that date to a considerable extent. There are six wells now located within a radius of three miles from well No. 1. One of them is dry. The remaining four range in production between a half million and three million cubic feet per day, when measured in the casing.

The last two wells have been drilled by the Greenville Natural Gas Company, with reference to obtaining a supply for the town of Greenville and intervening villages. Three dry wells have been drilled by the company in the vicinity of Greenville. The new wells are located on eighty acres leased by the company in Granville township, Mercer county, and are located twenty miles due north of Greenville, and near the line of the "Mackinaw" railroad.

The first well was brought in during the fall of 1887; the second, early in 1888. Well No. 1 was torpedoed and improved thereby. Well No. 2 is a much stronger well, and has not been torpedoed. The rock pressure is the same as that already found elsewhere in the field, viz., 350 to 375 pounds per square inch. The depth of the wells and the relation of the Trenton limestone to sea level are also virtually the same as in the St. Henry's wells already reported (see page 260).

The production of the wells was determined on February 27, 1888. The volume was calculated for a temperature of 50° F., the average surface temperature of this part of the state. The temperature of the escaping gas is about 35° F.

Well No. 1 yields on this basis 417,490 cubic feet *per diem.*
Well No. 2 yields on this basis 2,698,600 cubic feet *per diem.*

The united production is 3,116,090 per diem.

Well No. 2 is somewhat stronger than the Dwyer well No. 1, but no reliable figures were obtained from the latter. This well (Greenville No. 2) is thus found to be the second in strength of those that have been measured in the Mercer county field, the first place being held by the Doenzes well of Franklin township.

The record and experience of well No. 1 (Greenville Co.) have cleared up very satisfactorily an anomaly found in well No. 2, St. Henry's, described on page 261. The fragments of limestone thrown out by the explosion of the torpedo in the latter well proved to be a true carbonate of lime, of exceptional purity. It was inferred that these fragments

represented the gas-rock, and the difference of composition between this and the normal gas-rock was duly noted. It was found, however, in well No. 1, above named, that this true limestone constitutes the cap of the gas-rock which has the usual dolomitic composition. The driller describes this cap as very hard rock and entirely destitute of gas; this cap is probably not continuous on the large scale in any division of the field.

This field is evidently one of much value and promise. It is a part of the great Auglaize-Mercer field, to which scant justice has been done in the preceding pages, its development having mainly followed the completion of the account of that portion of the state.

St. Mary's and Lima are now supplied with abundance of gas from this field by a pipe-line, and other towns to the southward are sure to draw a supply from the same region.

Waterville, Perrysburg and Haskins.

Under this head a few facts will be given as to recent developments in the lower Maumee Valley.

In the preliminary report of 1886, attention was called to the fact that the Findlay break extends in a direction a little west of north, through Hancock, Wood and Lucas counties. There is a nearer approach to an anticline here than in most parts of the field, the eastern slope being quite steep. On this ridge of Trenton limestone, a few gas-wells of rather light volume have been found in the midst of generally unproductive territory. Several are located near Waterville, and one recently brought in above Perrysburg is reported by N. L. Hanson, Esq., to show an open pressure of two pounds in a two-inch pipe. This stands for a daily production of 1,140,000 cubic feet. It is the fifth well drilled by Perrysburg interests, and the first that possesses any value whatever.

At Haskins an oil well of moderate value has been struck within the last few months.

Lindsey and Gibsonburg.

Drilling has been continued in the western parts of Sandusky and Ottawa counties during the last few months with considerable force, and with some returns in the way of gas. At Lindsey the third well has proved to be a fair gas well, adequate in its present volume to the supply of the town. The well produces from a two-inch pipe 460,000 cubic feet of gas per day. The rock pressure is at least 500 pounds. The increase o pressure when the well is shut in is 100 pounds in one and three-fourths minutes, and 490 pounds in thirty minutes.

If the account could stop here, a favorable conclusion might be drawn in regard to this field. One fact remains to be added, viz., the presence of oil in the well. The Trenton limestone was reached at 1,241

feet below the surface and was penetrated but nine feet. The well was shot with twenty quarts of nitro-glycerine, and while the flow of gas was greatly increased, oil now comes with it. This is the threatening factor in all this portion of the field. The same state of things exists at Oak Harbor and Gibsonburg. The life of the wells is likely to be short under these conditions.

Trenton Limestone Oil.

Its Character and Uses.

The large production of oil actually realized from the Trenton limestone in Allen, Hancock and Wood counties has been described in Chapter III, and particularly on pages 168, 178-9, and 237-8. The possibilities of production vastly in excess of that which has thus far been realized, have also been pointed out in the same connections. The disposition made of the oil and the prices paid for it at different times since the production began, have also been in part noted, but the vital questions, as to its real value and uses to which it is best adapted, have been thus far postponed. A few words must be devoted to these questions now.

Trenton limestone oil is a typical limestone oil, dark in color, rather low in gravity, and containing a percentage of sulphuretted products which, though absolutely small, is relatively large. The last element makes itself offensive by a penetrating and characteristic odor, and resists expulsion with great stubbornness. The extremes of gravity noted in it are 31° and 42° B., at a temperature of 60° F., but the bulk of the fresh oil is included between 36° and 41° B. The oil of the North Baltimore field reaches the latter figure, and thus has an apparent advantage as a refining oil over the other fields, by one to three degrees, B.

The initial experiments in refining the new found oil were made in Pittsburgh and Toledo. The results seemed fairly favorable. The quality of the illuminating oil was good, though not perfect; but the percentage was reported as considerably lower than that of Pennsylvania oils, and the deodorization of the product was not complete. Presently the work of refining was begun at Lima and Findlay, in each case by local companies organized for the purpose. No large outlays were made. A little later, the Standard Oil company, which had already entered the new field in its usual line of service in transporting and storing the oil, established a very extensive refinery at Lima. Still later, other independent refineries were built at Lima and also at Bradner, Wood county. The refining of Trenton limestone oil is thus seen to be going forward on a large scale at the points named, and it

may be concluded that a full account can now be given of this very important element in the value of the field. Such, however, is far from being the case. On the one side, is the Standard Oil Company with its vast interests in the oil production of the entire country; on the other are the local companies, whose interests are mainly limited to the particular districts in which they are working.

The testimony given by these parties is discordant. The Standard Oil Company declared, a few months ago, through its representatives, that in planting $2,000,000 in the field (the amount must be very much greater at the present time), it had made a great mistake. It further declared that the expensive experiments conducted by it in seeking to obtain from Lima crude an illuminating oil that will fairly compete in open market with Pennsylvania oil had resulted in complete failure, and that out of 200,000 barrels refined, no oil that could be successfully used had been obtained. The company further averred that the only use that it had been able to find for the oil was for fuel. This testimony was given in the explanation of its policy in reducing the price of crude oil from forty cents per barrel, with which it set out, to fifteen cents per barrel, the rate that now prevails.

On the other hand, the local refining companies assert that they are obtaining perfectly satisfactory results in refining and deodorizing Trenton limestone oil. They are certainly turning out considerable quantities of refined oil which appears to have no difficulty in finding market at current rates.

In the hope that the true character and capabilities of the oil would be made known through the practical work that is going forward on so large a scale, the preparation of the present statement has been deferred to the last moment. The chemical analysis of the oil has in like manner been deferred, partly from the belief that laboratory results must be taken with considerable allowance as indicative of what can be obtained from practical operation carried on in the large way.

But as already shown, the testimony derived from the experience of the refining companies is contradictory, and if any scientific examination of the facts has been carried on by them, its results certainly have not been made public.

Under these circumstances Professor Lord, Chemist of the Survey, has undertaken at the last hour, a partial chemical examination of Trenton limestone oil, and the results obtained by him show at once the value of this line of inquiry and the need of a good deal more work in the same field.

The method of inquiry pursued in the investigation was the comparative one. Macksburg oil, the qualities of which are fairly well

known, and Lima oil, the constitution and composition of which are the problems to be solved, were subjected to the same process. Both oils were taken from fresh stocks. The distillation was carried on in glass retorts and was arrested before cracking of the oils was begun.

The results are as follows:

Macksburg Oil.	Trenton Limestone Oil.
Specific gravity of crude oil = 0.823 = 41°*B.*	*Specific gravity of crude oil* = 0.832 = 39°*B.*
Naptha under 0.73 spec. grav 16%	Naptha under 0:73 spec. grav 15%
Kerosene between 0.73 and 083..... 38%	Kerosene between 0.73 and 0.83..... 33%
Sulphur 0.025%	Sulphur 0.553%
	Sulphur in crude distillate ...0.52%
	Sulphur in refined distillate "odorless prime oil" ...0.36%

In a second specimen of refined and deodorized oil, the sulphur is found to be 0.22%.

If Bradford oil had been brought into the comparison, the results would have been more unlike than those that are here recorded. As it is, the Trenton limestone oil is seen to fall but little below Macksburg oil in its percentage of either naptha or kerosene. If the operation had been carried to the cracking point of the oils, it is probable that both would have gained proportionately.

The all-important difference between them is in the sulphur that they respectively contain. The Trenton limestone oil carries more than twenty times as much sulphur as the Macksburg oil. The tenacity with which the sulphur is held, is shown in the figures of the two lower columns. Almost the entire amount comes over in the distillate, and the final treatment that is believed by the refiner to remove it altogether, converting the distillate into "odorless, prime oil," is found by analysis to have reduced the offensive element by only one-third of the original amount. These figures as to sulphur are derived from but two refineries, it is true, and therefore apply only to the processes there in force, but there are some reasons for believing that other of the attempts at elimination are similarly unsuccessful. The offensive compound is masked, not removed. In regard to the figures here given, Professor Lord desires it to be understood, that while they stand for sulphur that is present in the oils, it is not certain that they show all the sulphur that is present. The method which he was obliged to use may possibly leave a small portion of this element behind.

That the entire removal of the sulphur can be effected by proper chemical knowledge and skill and at no great outlay there is no reason to doubt.

In conclusion the following statements seem warranted in regard to Trenton limestone oil.

1. This oil is inferior in value to the oil of the Bradford type on the following grounds: (*a*) it yields a smaller percentage of illuminating oil. (*b*) it suffers a larger percentage of loss in refining: (*c*) it contains offensive compounds of sulphur which must be removed before the oil is ready for market, and which are removed with some difficulty and expense.

2. The Trenton limestone oil appears to be nearly equal in value to Macksburg oil, aside from its sulphur contents. It will certainly yield forty-eight per cent. of naptha and kerosene above 0.83, and by "cracking," its production can probably be pushed to as high a figure as is reached by the latter.

3. The oil can be practically deodorized at comparatively small expense. It is at least brought into such condition that it is able to enter the market without serious disadvantage. Complete deodorization is claimed by most if not by all of the refineries, but this claim is not generally substantiated. It is thus far justified in but very few cases.

4. The best of the illuminating oil manufactured from it is indistinguishable in burning from the best oil of the Pennsylvania field, so far as the brightness, clearness and duration of the flame are concerned. It neither crusts the wick nor clouds the chimney of the lamp in which it is burned.

5. The lubricating oils and the other accessory products of refining are of excellent quality.

6. The present price of Lima oil, viz., 15 cents per barrel, forbids our learning in a practical way much of its real capabilities. The heart of it will be taken by the refiners, and the residue will be sold for fuel so long as this rate continues.

7. The present price of Lima oil is no measure of its real value, in fact, has no recognizable relation to its real value as compared with the value of Pennsylvania oil. The market is not an open one, but it is controlled by the investments made in the business of producing and refining oil elsewhere, and especially by the great stocks of eastern oil.

8. There is one use of Lima crude oil, in regard to the success of which no doubt remains, viz., its use as fuel. It is excellently adapted to the convenient and economical production of heat for very many purposes. It has been applied to ordinary stoves, to the production of steam in stationary boilers and to a limited extent in locomotives, to the heating of gas retorts, to the burning of lime, to puddling and reheating furnaces and to various other uses. The problem of applying it to these uses has been satisfactorily solved by the invention of several burners now in the market, but it is quite likely that improvements will be made in this line.

APPENDIX.

TABLE GIVING ELEVATIONS ABOVE SEA LEVEL IN THE SEVERAL COUNTIES OF OHIO.

In the accumulation and compilation of the data herewith printed, many persons have been engaged. The most extensive list of elevations published prior to the list given in the Secretary of State's report for 1886, was that of Mr. Henry Gannett, Chief Geographer of the United States Geological Survey. In 1884, this author published in a bulletin of the Survey, a Dictionary of Altitudes, covering points in all the states and territories. The list of elevations in Ohio, furnished in this volume, was made the basis of the table published in the report of Hon. James S. Robinson, Secretary of State, already referred to. A considerable amount of labor in the compilation of additional data was performed by Hon. Henry Luskey, formerly Commissioner of Labor Statistics of Ohio, but at this time employed in the office of the Secretary of State, and the list of elevations was considerably increased thereby. The additional data were furnished by various individuals. Professor C. N. Brown, of Ohio State University, contributed a number of figures derived from railroad surveys, and others were added by Wyndham C. Jones, Esq., Engineer of the Valley Railway, Cleveland, and still others were furnished from the records of the State Geological Survey. Everything available in the records of the Survey was turned over to this use. A few figures were taken from the determinations of the Ohio Meteorological Bureau.

This list has in turn been made the basis of the present collection of data. It has been somewhat expanded by the incorporation of facts from sundry sources, and is consequently the most comprehensive table yet published of the elevations of the surface of this State.

For no list of this character, however, can great accuracy be claimed until a careful comparison of data is secured. Such a comparison, it has not been found possible to include within the work of the Survey. Numerous discrepancies are known to exist in the figures that we are obliged to use. For example, the figures derived from the Toledo and Ohio Central Railway are found to be 8.8 feet lower at the crossing of

the Cincinnati, Washington and Baltimore Railroad, near Athens, than the levels of the latter road. So, also, the elevations of the Cleveland and Canton Railroad and of the Valley Railway disagree by seven feet at the crossing of these two roads, the levels of the Valley road being the higher. There are several such instances known, but, as before stated, it has not been found possible to correct the figures in this reprint.

The authorities on which the figures of the tables are based are chiefly railroad surveys. The grade of the road at the station named is supposed to be represented in the figures given. The levels credited to the Geological Survey are mostly barometric. In the tables the railroads will be designated by abbreviations, as follows:

Abbreviation.	*Name of Railroad.*
A. & P. R. R.	Ashtabula and Pittsburgh.
B. & O. R. R.	Baltimore and Ohio.
B., Z. & C. R. R.	Bellaire, Zanesville and Cincinnati.
C. O. R. R.	Central Ohio (B. & O.).
C. & A. R. R.	Chicago and Atlantic.
C., St. L. & P. R. R.	Chicago, St. Louis and Pittsburgh.
C., G. & P. R. R.	Cincinnati, Georgetown and Portsmouth.
C., H. & D. R. R.	Cincinnati, Hamilton and Dayton.
C., H. & I. R. R.	Cincinnati, Hamilton and Indianapolis.
C., I., St. L. & C. R. R.	Cincinnati, Indianapolis, St. Louis and Chicago.
C & M. V. R. R.	Cincinnati and Muskingum Valley.
C. N. R. R.	Cincinnati Northern.
C., W. & B. R. R.	Cincinnati, Washington and Baltimore.
C., A. & C. R. R.	Cleveland, Akron and Columbus.
C. & C. R. R.	Cleveland and Canton.
C. & M. R. R.	Cleveland and Marietta.
C. & P. R. R.	Cleveland and Pittsburgh.
C. & W. R. R.	Cleveland and Wheeling.
C., C., C. & I. R. R.	Cleveland, Columbus, Cincinnati and Indianapolis.
C., L. & W. R. R.	Cleveland, Lorain and Wheeling.
D. & I. R. R.	Dayton and Ironton.
D. & M. R. R.	Dayton and Michigan.
I., B. & W. R. R.	Indianapolis, Burlington and Western.
L. E. & W. R. R.	Lake Erie and Western.
L. S. & M. S. R. R.	Lake Shore and Michigan Southern.
N. Y., P. & O. R. R.	New York, Pennsylvania and Ohio.
O. & N. W. R. R.	Ohio and Northwestern.
P., C. & St. L. R. R.	Pittsburgh, Cincinnati and St. Louis.
P., Ft. W. & C. R. R.	Pittsburgh, Fort Wayne and Chicago.
S. V. R. R.	Scioto Valley.
T., C. & S. R. R.	Toledo, Columbus and Southern.
T. & O. C. R. R.	Toledo and Ohio Central.
V. R. R.	Valley.
W. & L. E. R. R.	Wheeling and Lake Erie.

TABLE GIVING ELEVATIONS ABOVE SEA LEVEL IN THE COUNTIES OF OHIO.

(The elevation of Lake Erie above sea level is counted 573 feet.)

Station.	Authority.	Elevation.
ADAMS COUNTY.		
Mineral Springs	O. & N. W. R. R.	757.
Newport	O. & N. W. R. R.	660.
Peebles	O. & N. W. R. R.	820.
Winchester	O. & N. W. R. R.	980.
West Union	Ohio Geological Survey, Whittlesey	983.
ALLEN COUNTY.		
Beaver Dam	L. E. & W. R. R.	863.
Bluffton	L. E. & W. R. R.	834.
Cairo	D. & M. R. R.	814.
Delphos	P., Ft. W. & C. R. R.	786.
Elida	P., Ft. W. & C. R. R.	798.
Harrods	C. & A. R. R.	1012.
Lafayette	P., Ft. W. & C. R. R.	936.
Lima, P., Ft. W. & C. R'y	P., Ft. W. & C. R. R.	874.
Lima, D. & M. R'y	D. & M. R. R.	875.
Lima, L. E. & W. R'y	L. E. & W. R. R.	885.
Lima	C. & A. R. R.	903.
Spencerville, Lock 15	Miami & Erie Canal	847.
Spencerville	C. & A. R. R.	851.
Summit bet Westminster & Harrods	C. & A. R. R.	1032.
Westminster	C. & A. R. R.	997.
ASHLAND COUNTY.		
Ashland	N. Y., P. & O. R. R.	1079.
Loudonville	P., Ft. W. & C. R. R.	985.
Nankin	N. Y., P. & O. R. R.	1123.
Perrysville	P., Ft. W. & C. R. R.	1006.
Polk	N. Y., P. & O. R. R.	1241.
ASHTABULA COUNTY.		
Amboy	L. S. & M. S. R. R.	681.
Andover	L. S. & M. S. R. R., Franklin Div.	1095.
Andover, Geodetic Station	U. S. Lake Survey	1191.
Ashtabula	L. S. & M. S. R. R.	648.
Ashtabula	A. & P. R. R.	688.
Ashtabula, Harbor	A. & P. R. R.	580.
Conneaut	L. S. & M. S. R. R.	652.
Dorset	L. S. & M. S. R. R.	1018.
Geneva	L. S. & M. S. R. R.	668.
Jefferson	L. S. & M. S. R. R.	941.
Kingsville	L. S. & M. S. R. R.	672.
Leon	L. S. & M. S. R. R.	1114.
Munson Hill	A. & P. R. R.	866.
New Lyme	A. & P. R. R.	906.
Orwell	A. & P. R. R.	936.
Plymouth	L. S. & M. S. R. R.	854.
Richmond	L. S. & M. S. R. R.	1114.

Station.	Authority.	Elevation.
ASHTABULA COUNTY—Concluded.		
Rome	A. & P. R. R.	884.
Saybrook	L. S. & M. S. R. R.	651.
Simon's	L. S. & M. S. R. R.	1057.
State Line	L. S. & M. S. R. R.	652.
ATHENS COUNTY.		
Athens	C., H. V. & T. R. R.	655.
Athens	City Hall—Hibbard	714.
Athens, Hocking Canal	C., W. & B. R. R.	658.
Athens, crossing C., W. & B. R. R.	T. & O. C. R. R.	646.
Bessemer	C., H. V. & T. R. R.	681.
Big Run	C., W. & B. R. R.	656.
Buchtel	C., H. V. & T. R. R.	687.
Canaanville	U. S. Coast & Geodetic Survey	624.32
Chauncey	T. & O. C. R. R.	659.
Coolville	C., W. & B. R. R.	630.
Floodwood	C., H. V. & T. R. R.	670.
Glouster	T. & O. C. R. R.	681.
Guysville	U. S. Coast & Geodetic Survey	622.463
Hebbardsville	T. & O. C. R. R.	672.
King's	C., W. & B. R. R.	612.
Lee	T. & O. C. R. R.	742.
Lick Run	C., H. V. & T. R. R.	687.
Marshfield	C., W. & B. R. R.	826.
Millfield	T. & O. C. R. R.	663.
Mineral City	C., W. & B. R. R.	726.
Nelsonville	C., H. V. & T. R. R.	681.
New England	C., W. & B. R. R.	808.
Salina	C., H. V. & T. R. R.	659.
Stewart, ¾ miles West of	U. S. Coast & Geodetic Survey	616.994
Stewart, 1¼ miles East of	U. S. Coast & Geodetic Survey	615.921
Torch	C., W. & B. R. R.	723.
Trimble	T. & O. C. R. R.	672.
AUGLAIZE COUNTY.		
Baker Bridge, on Kossuth pike	Samuel Craig	840.
Bitler's	" "	1084.
Bowdle Church	" "	1031.
Bridge at Kent's	" "	908.
County Line, on Sidney pike	" "	1008.
County Line, on Hardin pike	" "	952.
Cridersville, level of town	" "	888.
Cridersville	D. & M. R. R.	887.
Five Points	Samuel Craig	1030.
Fryburg	" "	980.
Glynwood	" "	859.
Kossuth, level of town	" "	838.
Knoxville	" "	902.
New Bremen	L. E. & W. R. R.	1038.
New Bremen	Canal level	960.
New Hampshire	Samuel Craig	1028
Rinehart's	" "	989.
Santa Fe	" "	1004.
St. John's, at Bitler House	" "	1003.
St. Mary's, at Dieker House	" "	875.

Station.	Authority.	Elevation.
AUGLAIZE COUNTY—Concluded.		
St. Mary's, Lock 13	Miami & Erie Canal	864.25
Uniopolis	Samuel Craig	933.
Wapakoneta	D. & M. R. R.	891.
Wapakoneta, Court House floor	Samuel Craig	892.
Waynesfield	" "	1059.
West Prairie	" "	1022.
BELMONT COUNTY.		
Ambler	B., Z. & C. R. R.	670.
Armstrong's Mills	B., Z. & C. R. R.	794.
Barnesville	C. O. (B. & O.) R. R.	1234.
Barton	C., L. & W. R. R.	796.
Bellaire	C. & P. R. R.	655.
Belmont	C. O. (B. & O.) R. R.	1156.
Bethel	B., Z. & C. R. R.	1255.
Bridgeport	C. & P. R. R.	559.
Bruce	C., L. & W. R. R.	989.
Burton's	C. O. (B. & O.) R. R.	1268.
Burrs's Mill	C. O. (B. & O.) R. R.	1226.
Captina	B., Z. & C. R. R.	778.
Children's Home	C. O. (B. & O.) R. R.	1274.
Crab Apple	B., Z. & C. R. R.	952.
Fairpoint	C., L. & W. R. R.	913.
Flushing	C., L. & W. R. R.	1118.
Franklin	C. O. (B. & O.) R. R.	783.
Glencoe	C. O. (B. & O.) R. R.	833.
Holloway	C., L. & W. R. R.	911.
Irwin	B., Z. & C. R. R.	932.
Jacobsburg	B., Z. & C. R. R.	1330.
Lafferty	C., L. & W. R. R.	1027.
Lewis' Mills	C. O. (B. & O.) R. R.	1035.
Marbletown	C. O. (B. & O.) R. R.	919.
Martin's Ferry	C. & P. R. R.	659.
Neff's Siding	C. O. (B. & O.) R. R.	727.
Pasco	C., L. & W. R. R.	731.
Quincy	C. O. (B. & O.) R. R.	722.
Warnock	C. O. (B. & O.) R. R.	943.
Wegee	B. Z. & C. R. R.	645.
West Wheeling	C., L. & W. R. R.	648.
West Wheeling, low water in Ohio river	C., L. & W. R. R.	618.
West Wheeling	C. & P. R. R.	659.
St. Clairsville	Kinney	1170.
BROWN COUNTY.		
Aberdeen, Main and Cross streets	Ohio Geological Survey, Whittlesey	545.
County line between Brown and Clermont counties	C., G. & P. R. R.	937.
Georgetown	C., G. & P. R. R.	942.
Georgetown	Col. & Mays. R. R.	945.
Hamersville, water tank	C., G. & P. R. R.	976.
Ohio Pike Crossing, East of Hamersville	C., G. & P. R. R.	977.
Mt. Oreb	O. & N. W. R. R.	923.
Sardinia	O. & N. W. R. R.	963.

Station.	Authority.	Elevation.
Brown County—Concluded.		
South Fincastle	O. & N. W. R. R.	1081.
White Oak Viaduct	C., G. & P. R. R.	871.
White Oak Creek, bed of	C., G. & P. R. R	768.
Butler County.		
Carlisle	C, H. & D R. R.	696.
College Corner	C, H. & I. R. R.	990.
Gano	C., C., C & I. R. R.	661.
Hamilton	C, H & D. R. R.	597.
Hamilton, Basin	Miami Canal	610.
Hamilton, low water in Miami river	Ohio Geological Survey—Orton	563.
Henderson	C., C., C. & I. R. R.	656.
Jacksonburgh	Ohio Geological Survey—Orton	975.
Jones Station	C., H. & D. R. R.	672.
Kyle's	C., C., C. & I. R. R.	718.
Maud's	C., C., C. & I. R. R.	759.
Middletown	C, C., C. & I. R. R.	667.
Middletown, Canal level	Ohio Geological Survey—Orton	643.
Oxford	C., H. & I. R. R.	918.
Oxford, highest ground in	Ohio Geological Survey—Orton	964.
Smiley's Hill	Ohio Geological Survey—Orton	995.
Somerville	Ohio Geological Survey—Orton	766.
Oxford township, North-East corner	Ohio Geological Survey—Orton	1033.
West Chester	C., C., C. & I. R. R	745.
Carroll County.		
Carrolton	C. & C. R. R.	1142.
Dell Roy	C. & C. R. R.	929.
Malvern	C. & P. R. R.	999.
Oneida Mills	C. & P. R. R.	1016.
Sherrodsville	C. & C. R. R.	914.
Summit between Oneida and Carrollton	C. & C. R. R.	1153.
Champaign County.		
Catawba	C, C, C. & I. R. R.	1065.
Kennard	N. Y., P. & O. R. R	1174.
Kingston	N. Y., P. & O. R. R.	1097.
Mechanicsburg	C., C., C. & I. R. R.	1058.
Mechanicsburg, summit near	Ohio Geological Survey, Whittlesey	1118.
Mingo	N. Y, P. & O. R. R	1206.
North Lewisburg	N. Y., P. & O. R. R.	1082.
St. Paris	P., C. & St. L. R. R.	1238.
Taylorstown	N. Y, P. & O. R. R.	1091.
Urbana	N. Y., P. & O. R. R.	1027.
Urbana, P., C. & St. L. crossing	N. Y., P & O. R. R.	1030.
Urbana	I., B. & W. R. R.	1031.
Clarke County.		
Bowlusville	N. Y., P & O. R. R.	966.
Enon	P., C. & St. L. R R	1024.
Hennessy's	P., C. & St. L. R R.	1031.
Moorefield	C., C, C. & I. R. R.	1021.
Selma	P., C. & St. L. R. R.	1083.

Station.	Authority.	Elevation.
CLARKE COUNTY—Concluded.		
Snyder's	N. Y., P. & O. R. R.	900.
South Charleston	P., C. & St. L. R. R.	1126.
Springfield	N. Y., P. & O. R. R.	908.
Springfield, Union depot	P., C. & St. L. R. R.	991.
CLERMONT COUNTY.		
Aurelia	C., G. & P. R. R.	886.
Batavia	O. & N. W. R. R.	585.
Bantam	Ohio Geological Survey—Orton	905.
Bethel	Ohio Geological Survey—Orton	930.
Bethel, Station	C., G. & P. R. R.	905.
Branch Hill	P., C. & St. L. R. R.	590.
Centerville	C., G. & P. R. R.	870.
Cohoon	O. & N. W. R. R.	565.
Dry Run, trestle over on New Richmond branch	Cin. & E. R. R.	877.
Dry Run, bed of	Cin. & E. R. R.	836.
Glen Este	C., G. & P. R. R.	876.
Kyle's	C., G. & P. R. R.	860.
Loveland	U. S. Coast and Geodetic Survey	582 352
Loveland, crossing P., C. & St. L. R. R.	C., W. & B. R. R.	594.
Miamiville	P., C. & St. L. R. R.	580.
Milford	P., C. & St. L. R. R.	552.
Mt. Carmel	C., G. & P. R. R.	897.
New Richmond branch of C. & E. R. R. at crossing	C., G. & E. R. R.	834.
Olive Branch	C., G. & P. R. R.	832.
Poplar Creek, bed of	C., G. & P. R. R.	836.
Poplar Creek, East end of trestle over	C., G. & P. R. R.	876.
Salt Run, bed of	C., G. & P. R. R.	717.
Salt Run, trestle No. 22, over	C., G. & P. R. R.	855.
Sugar Tree Run, bed of	C., G. & P. R. R.	844.
Sugar Tree Run, trestle over	C., G. & P. R. R.	869.
Ulrey's Run, trestle over East end of	C., G. & P. R. R.	870.
Williamsburg	O. & N. W. R. R.	823.
Withamsville, summit near	Ohio Geological Survey—Orton	936.
CLINTON COUNTY.		
Anderson's Fork	C. & C. M. R. R.	1055.
Blanchester	C., W. & B. R. R.	977.
Clarksville	C. & M. V. R. R.	833.
Clinton Valley	U. S. Coast and Geodetic Survey	990.553
Clinton Valley	C. & C. M. R. R.	1000.
Cowan's Creek	C. & C. M. R. R.	973.
Cuba	C. & C. M. R. R.	1047.
East Fork	C. & C. M. R. R.	967.
Lytle's Creek	C. & C. M. R. R.	1000.
Marlow's	C. & C. M. R. R.	1059.
Martinsville	C., W. & B. R. R.	1043.
Martinsville	U. S. Coast and Geodetic Survey	1057.125
Melvin	C. & C. M. R. R.	1070.
Reeseville	C. & M. V. R. R.	1086.
Sabina	C. & M. V. R. R.	1066.
Sabina	C. & C. M. R. R.	1051.

Station.	Authority.	Elevation.
CLINTON COUNTY—Concluded.		
Sligo	C. & M. V. R. R.	901.
Summit between Reeseville and Melvin	C. & C. M. R. R.	1125.
Todd's Fork	C. & C. M. R. R.	1042.
Vienna	C., W. & B. R. R.	1130.
Vienna, summit near	Ohio Geological Survey—Orton	1169.
Wilmington	C. & M. V. R. R.	1017.
Wilmington	C. & C. M. R. R.	1035.
COLUMBIANA COUNTY.		
Bayard	C. & P. R. R.	1076.
Columbiana	P., Ft. W. & C. R. R.	1114.
East Liverpool	C. & P. R. R.	693.
East Palestine	P., Ft. W. & C. R. R.	1014.
East Rochester	C. & P. R. R.	1082.
Franklin	N. Y., P. & O. R. R.	1079.
Homeworth	C. & P. R. R.	1150.
Kensington	C. & P. R. R.	1130.
Leetonia	P., Ft. W. & C. R. R.	1017.
Mahoning Summit	Ohio Geological Survey, Newberry	1200.
Moultrie	C. & P. R. R.	1103.
New Lisbon	N. Y., P. & O. R. R.	958.
New Waterford	P., Ft. W. & C. R. R.	1076.
Robbins' Station	N. Y., P. & O. R. R.	982.
Round Knob	Ohio Geological Survey, Newberry	1417.
Salem	P., Ft. W. & C. R. R.	1173.
Salem, highest ground in corporation	J. B. Strawn	1334.
Salem	Ohio Geological Survey, Newberry	1193.
Sandy Summit	Ohio Geological Survey, Newberry	1185.
Salineville	C. & P. R. R.	879.
Teegarden	N. Y., P. & O. R. R.	1043.
Wellsville	C. & P. R. R.	688.
Yellow Creek Summit	Ohio Geological Survey, Newberry	1116.
Yellow Creek Hills	Ohio Geological Survey, Newberry	1256.
COSHOCTON COUNTY.		
Avondale	C. & C. R. R.	785.
Conesville	P., C. & St. L. R. R.	738.
Coshocton	P., C. & St. L. R. R.	771.
Oxford	P., C. & St. L. R. R.	793.
Rock Run	P., C. & St. L. R. R.	758.
Roscoe	Ohio canal	754.52
Rowville Cut	C. & C. R. R.	1067.
West Lafayette	P., C. & St. L. R. R.	800.
CRAWFORD COUNTY.		
Broken Sword Creek	P., Ft. W. & C. R. R.	916.
Bucyrus	P., Ft. W. & C. R. R.	930.
Bucyrus, crossing P., Ft. W. & C. R. R.	T. & O. C. R. R.	1001.
Crestline	P., Ft. W. & C. R. R.	1162.
Crestline, summit near	C., C., C. & I. R. R.	1177.
Galion	N. Y., P. & O. R. R.	1169.
Leesville	P., Ft. W. & C. R. R.	1135.
Lemert	T. & O. C. R. R.	975.

Station.	Authority.	Elevation.
Crawford County—Concluded.		
New Winchester	T. & O. C. R. R.	1022.
Robinson	P., Ft. W. & C. R. R.	1073.
Cuyahoga County.		
Bedford	C. & P. R. R.	941.
Berea	C., C., C. & I. R. R.	793.
Brecksville	Valley R. R.	633.
Cleveland	Union Depot	583.
Cleveland, Euclid Ave.	L. S. & M. S. R. R.	627.
Cleveland, Signal Station	U. S. Signal Office	690.
Cleveland, Newburgh	C. & P. R. R.	797.
Cleveland, Newburgh	N. Y., P. & O. R. R.	813.
Euclid	L. S. & M. S. R. R.	627.
Independence	Valley R. R.	603.
Independence, Lock 13	Ohio Canal	661.4
Olmstead	C., C., C. & I. R. R.	782.
Olmstead Falls	L. S. & M. S. R. R.	770.
Olmstead Falls, Geodetic Station	U. S. Lake Survey	794.
Randall	N. Y., P. & O. R. R.	1046.
Rockport	L. S. & M. S. R. R.	884.
Rockport, Geodetic Station	U. S. Lake Survey	781.
Royalton	U. S. Lake Survey.	1272.
Solon	N. Y., P. & O. R. R.	1041.
Warrensville, Geodetic Station	U. S. Lake Survey	1214.
Darke County.		
Ansonia	C., C., C. & I. R. R.	1006.
Arcanum	I., B. & W. R. R.	1054.
Bruss	I., B. & W. R. R.	1092.
Clark's	I., B. & W. R. R.	1080.
Dawn	C., C., C. & I. R. R.	1018.
Greenville	P., C. & St. L. R. R.	1055.
Hollansburg	I., B. & W. R. R.	1150.
Ithica	Lindemuth	989.
Union City	C., C., C. & I. R. R.	1105.
Versailles	C., C., C. & I. R. R.	977.
Weaver's	P., C. & St. L. R. R.	977.
Defiance County.		
Defiance	B. & O. R. R.	712.
Defiance	W., St. L. & P. R. R.	698.
Defiance, Maumee river	W., St. L. & P. R. R.	648.
Defiance	Miami and Erie Canal	667.
Fort Defiance	Canal level—Whittlesey	671.
Hicksville	B. & O. R. R.	762.
Mark Center	B. & O. R. R.	731.
Prairie Run	D. & M. R. R.	700.
Standley	D. & M. R. R.	731.
White's Mill	D. & M. R. R.	717.
Delaware County.		
Ashley	C., C., C. & I. R. R.	985.
Berlin	C., C., C. & I. R. R.	954.
Condit	C., A. & C. R. R.	1086.

Station.	Authority.	Elevation.
DELAWARE COUNTY—Concluded.		
Delaware	C., C., C & I. R. R	903.
Delaware	C., H. V. & T. R. R	927.
Eden	C., C., C. & I. R. R	975.
Galena	C., A. & C. R. R	923.
Hyatt's	C., H. V. & T. R. R	933.
Lewis Center	C., C., C & I. R. R	960.
Ostrander	C., C., C. & I. R. R	934.
Peerless	T. & O. C. R. R	1179.
Powell	C., H. V. & T. R. R	918.
Radnor	C., H. V. & T. R. R	953.
Summit	C., H. V. & T. R. R	972.
Sunbury	C., A. & C. R. R	970.
ERIE COUNTY.		
Ceylon	L. S. & M. S. R. R	609.
Huron	L. S. & M. S. R. R	598.
Kelley's Island, Geodetic Station	U. S. Lake Survey	614.
Prout's	B. & O. R. R	708.
Sandusky, city base	City Engineer	587.
Sandusky, L. S. & M. S. R. R. Station	L. S. & M. S. R. R	593.
Sandusky, I., B. & W. R. R. Station	I., B. & W. R. R	598.
Sandusky, B. & O. R. R. Station	B. & O. R. R	609.
Sandusky, Geodetic Station	U. S. Lake Survey	632.
Sandusky, Signal Station	U. S. Signal Office	639.
Venice	L. S. & M. S. R. R	585.
Vermillion	L. S. & M. S. R. R	596.
FAIRFIELD COUNTY.		
Amanda	B., Z. & C. R. R	946.
Bremen	C. & M. V. R. R	831.
Bremen	T. & O. C. R. R	789.
Carroll	C., H. V. & T. R. R	835.
Hadley Junction	T. & O. C. R. R	883.
Hooker	C., H. V. & T. R. R	835.
Lancaster	C., H. V. & T. R. R	854.
Lancaster, summit of Ohio canal	C., H. V. & T. R. R	831.
Lancaster, Court House	C., H. V. & T. R. R	898.
Lockville	C., H. V. & T. R. R	795.
Millersport	T. & O. C. R. R	906.
Pleasantville	T. & O. C. R. R	904.
Rushville	T. & O. C. R. R	859.
Sugar Grove	C., H. V. & T. R. R	769.
FAYETTE COUNTY.		
Bloomingburg	C. & C. M. R. R	988.
Compton's Creek	C. & C. M. R. R	934.
Jasper Mills	C. & C. M. R. R	1008.
Madison	C. & C. M. R. R	930.
Paint Creek	C. & C. M. R. R	960.
Paint Creek, East Fork	C. & C. M. R. R	967.
Paint Creek, North Fork	C. & C. M. R. R	905.
Rattlesnake (rail)	C. & C. M. R. R	1026.
Sugar Creek	C. & C. M. R. R	994.
Washington C. H.	C. & M. V. R. R	983.

Station.	Authority.	Elevation.
Fayette County—Concluded.		
Washington C. H, bottom step of Court House	City Engineer—Kennedy	989.
Washington	C. & C. M. R. R.	973.
White Oak	C. & C. M. R. R.	925.
Franklin County.		
Alton	P., C. & St. L. R. R.	928.
Briggs	C. & C. M. R. R.	774.
Caldwell	Scioto Valley R. R.	811.
Columbus, Union Depot	C., H. V. & T. R. R.	748.
Columbus, N. E. cor. of State House	C., H. V. & T. R. R.	781.
Columbus, Scioto Val. R'y crossing	C, H. V. & T. R. R.	763.
Columbus, Starch Factory	C., H. V. & T. R. R.	738.
Columbus, Signal Office	U S Signal Office	805.
Columbus, Ohio State University	Ohio Geological Survey—Orton	768.
Edwards Station	C., H. V. & T. R. R.	755.
Elmwood	C., H. V. & T. R. R.	844.
Grove City	C., & C. M. R. R	960.
Groveport	C., H. V. & T. R. R.	738.
Lockbourne	Scioto Valley R. R.	720.
Morgan's	C. & C. M. R. R.	835.
Olentangy	C, H. V. & T. R. R.	822.
Pleasant Corners	C & C. M. R. R.	993.
Reese's	Scioto Valley R. R.	735.
Scioto River	C. & C. M. R. R.	735.
Sullivant's	P., C. & St. L. R. R.	834.
Westerville	C., A & C. R. R.	875.
Winchester	C., H. V. & T. R. R.	769.
Worthington	C., C., C. & I. R. R.	913.
Fulton County.		
Archbald	L. S. & M. S. R. R.	730.
Delta	L. S & M. S. R. R.	819.
Pettisville	L. S. & M. S. R. R.	753.
Swanton	L S & M S. R. R.	684.
Wauseon	L. S. & M S. R. R.	768.
Wauseon, summit	L. S. & M. S. R. R.	780.
Gallia County.		
Addison	C, H. V. & T. R. R.	570.
Cheshire	C., H. V. & T. R. R.	568.
Evergreen	C., H. V. & T. R. R.	690.
Ewington	C., H. V. & T. R. R.	677.
Gallipolis	C., H. V & T. R. R.	561.
Kerr's	C, H. V. & T. R. R.	591.
Mill's	C., H. V. & T. R. R.	564.
Niles	C, H V. & T. R. R.	696.
Point Pleasant	C, H. V. & T. R. R.	570.
Porter	C., H. V. & T. R R.	698.
Vinton	C., H. V. & T. R. R.	606.

Station.	Authority.	Elevation.
GEAUGA COUNTY.		
Chester, Geodetic Station	U. S. Lake Survey	1292.
Claridon, Geodetic Station	U. S. Lake Survey	1366.
Summit, Cuyahoga & Chagrin rivers	Ohio Geological Survey, Whittlesey	1202.
GREENE COUNTY.		
Beaver	P., C. & St. L. R R	808.
Berry's Hill	Ohio Geological Survey—Orton	992.
Cedarville	P., C. & St. L. R. R.	1035.
Claysville	P., C. & St. L. R. R.	756.
Goe's	P., C. & St. L. R. R.	863.
Harbine's	P., C. & St. L. R. R.	806.
Jamestown	D. & I. R R	1071.
Kneisley	C., C., C. & I. R. R.	802.
Monroe, summit	D. & I R. R	1063.
Oldtown	Ohio Geological Survey—Orton	828.
Osborn	C, C, C. & I. R. R.	830.
Pearce's	P, C. & St. L. R R	1029.
Spring Valley	P., C & St. L. R. R.	758.
Xenia	P., C. & St L. R. R	928.
Yellow Springs	P., C. & St. L. R. R.	978.
GUERNSEY COUNTY.		
Bailey's Mills	C. O. (B. & O.) R. R.	922.
Byesville	C. & M. R. R.	809.
Cambridge	C & M. R. R.	803.
Campbell's	C. O. (B & O.) R. R	805.
Cassel's	C. O. (B. & O.) R R	806.
Gibson's	C. O (B. & O.) R. R.	833.
Guernsey	C. & M. R R	785.
Guernsey, Coal Works	C. O. (B. & O.) R. R.	803.
Kimbolton	C. & M. R. R.	790.
Miller's	C & M. R. R.	783.
Morgan Junction	C O. (B & O) R. R.	824.
Nicholson	C. & M R. R.	795.
Norris Coal Works	C. O. (B. & O.) R. R.	807.
Oldham's	C. & M. R. R.	800.
Point Pleasant	C & M. R. R.	805.
Quaker City	C. O. (B & O.) R R.	874.
St. Clair Road Crossing	C. O (B. & O.) R. R.	853.
Spencer's	C. O. (B. & O) R. R.	882.
HAMILTON COUNTY.		
Ballou	C. N. R R.	848.
Batavia Junction	P., C. & St. L. R R.	491.
Blue Ash	C. N. R. R.	859.
Brachman's	C, G. & P. R. R.	713.
California	C, G. & P R. R.	540.
Camp Dennison	P., C. & St. L. R. R.	570.
Carthage	C., C., C. & I. R. R.	551.
Cedar Point	C., G. & P. R. R.	726.
Cherry Grove	C., G & P. R. R.	847.
Chester Park	C., C., C. & I. R. R.	508.
Cincinnati	Low water city datum	440.

Station.	Authority.	Elevation.
HAMILTON COUNTY—Concluded.		
Cincinnati, C., N. O. & T. P. R. R. depot	C., N. O. & T. P. R. R.	503.
Cincinnati, C. N. R. R. depot	C. N. R. R.	545.
Cincinnati, Signal Station	U. S. Signal Office	620.
Cleves	C., I., St. L. & C. R. R.	497.
Columbia	C., G. & P. R. R.	503.
Cumminsville	U. S. Coast and Geodetic Survey	506.861
Delhi	C., I., St. L. & C. R. R.	502.
Delta	P., C. & St. L. R. R.	504.
Forestville	C., G. & P. R. R.	834.
Fruit Hill	C., G. & P. R. R.	819.
Glendale	C., H. & D. R. R.	640.
Hazewood	C. N. R. R.	842.
Idlewild	C. N. R. R.	700.
Kennedy	C. N. R. R.	743.
Linwood	P., C. & St. L. R. R.	503.
Mt. Washington	C., G. & P. R. R.	766.
Newtown	P., C. & St. L. R. R.	494.
New Richmond Junction	O. & N. W. R. R.	530.
North Bend	C., I., St. L. & C. R. R.	497.
Norwood	C. N. R. R.	626.
Plainville	P., C. & St. L. R. R.	492.
Pendleton	P., C. & St. L. R. R.	519.
Pleasant Ridge	C. N. R. R.	658.
Red Bank	P., C. & St. L. R. R.	501.
Remington, west of C. W. & B. Station	U. S. Coast and Geodetic Survey	591.322
Sharon	C., C., C. & I. R. R.	601.
Silverton	C. N. R. R.	825.
Sycamore Creek, west of Remington	U. S. Coast and Geodetic Survey	591 322
Terrace Park	P., C. & St. L. R. R.	555.
Undercliff	P., C. & St. L. R. R.	495.
Valley Junction	C., I., St. L. & C. R. R.	499.
HANCOCK COUNTY.		
Arcadia	L. E. & W. R. R.	806.
Arlington	T. & S. R. R.	862.
Findlay	L. E. & W. R. R.	782.
Godsend, water tank	B. & O. R. R.	750.
Rawson	L. E. & W. R. R.	821.
Stuartsville	T. & S. R. R.	815.
Van Buren	T. & S. R. R.	782.
HARDIN COUNTY		
Ada	P., Ft. W. & C. R. R.	956.
Blanchard's Fork	P., Ft. W. & C. R. R.	900.
Dunkirk	P., Ft. W. & C. R. R.	949.
Forest	P., Ft. W. & C. R. R.	938.
Hog Creek Marsh	P., Ft. W. & C. R. R.	947.
Kenton	I., B. & W. R. R.	1015.
Mt. Victory	C., C., C. & I. R. R.	1036.
Preston	C. & A. R. R.	1007.
Ridgeway	C., C., C. & I. R. R.	1059.
Scioto River, bed of	I., B. & W. R. R.	953.
Silver Creek, summit	I., B. & W. R. R.	1118.

Station.	Authority.	Elevation
HARRISON COUNTY.		
Butler	C., L. & W. R R	889.
Cadiz	P., C. & St. L. R. R	1206.
Cadiz, Court House, water table	Jacob Jarvis	1270.
Cadiz Junction	P., C. & St. L. R. R	1091.
Crawford's Station	P., C. & St L. R. R	1258.
Fairview	P., C. & St. L. R. R	1011.
Folk's Station	P., C. & St. L. R. R	1217.
Freeport	C., L. & W. R. R	882.
Hall's Station	C., L. & W. R. R	1236.
Mastersville	P., C. & St. L. R. R	936.
Miller's	P., C. & St. L. R. R	1007.
New Market	P., C. & St. L. R. R	959.
Philadelphia Road	P., C. & St. L. R. R	858.
Summit on W. & L. E. Survey, two miles N. W. of Cadiz	W. & L. E. R. R	1307.
HENRY COUNTY.		
Alma	D. & M. R. R	710.
Deshler	B. & O. R. R	721.
Hamler	B. & O. R. R	723.
Holgate	B. & O. R. R	722.
Liberty Center	W., St. L & P. R. R	683.
Napoleon	W., St. L. & P. R. R	680.
Sand Hill	W., St. L. & P. R. R	739.
Texas, Lock 12	Miami & Erie Canal	661.4
HIGHLAND COUNTY.		
Bald Mountain, or Slate Knob	By barometer—Orton	1250.
Carmel	Ohio Geological Survey—Orton	939.
Danville	Ohio Geological Survey—Orton	1065.
Fisher's Knob	By barometer—Orton	1300.
Fort Hill	By barometer—Locke	1232.
Greenfield	C, W. & B. R. R	893.
Hillsboro	C., W. & B. R. R	1075.
Hillsboro	Col. & Maysv. R. R	1056.
Hillsboro, Court House	Ohio Geological Survey—Orton	1129.
Hillsboro, College Hill	Ohio Geological Survey—Orton	1140.
Hillsboro, Lilley's Hill	Ohio Geological Survey—Orton	1165.
Leesburg	C., W. & B. R. R	1030.
Long Lick Mountain	By barometer—Orton	1254.
Lynchburg (railroad grade)	Ohio Geological Survey—Orton	1001.
Marshall	Ohio Geological Survey—Orton	1031.
Monroe	Ohio Geological Survey—Orton	938.
Paint Creek	C., W. & B. R. R	896.
Rapids Forge Mountain	By barometer—Orton	1160.
Samantha	Ohio Geological Survey—Orton	1124.
Samantha, burying ground hill near	By barometer—Orton	1214.
Sinking Springs	Ohio Geological Survey, Whittlesey	723.
Stultz's Mountain	By barometer—Orton	1325.
Summit, bet. Lexington & Vienna	Ohio Geological Survey—Orton	1170.
HOCKING COUNTY.		
Carbon Hill	C., H. V. & T. R. R	697.
Enterprise	C., H. V. & T. R. R	747.
Falls Mills	C., H. V. & T. R. R	736.
Gore	C., H. V. & T. R. R	763.
Greendale	C., H. V. & T. R. R	709.
Haydenville	C., H. V. & T. R. R	705.

Station.	Authority.	Elevation.
Hocking County—Concluded.		
Logan	C., H. V. & T. R. R	728.
Logan, top of Water Falls at Court House	C., H. V. & T. R. R	742.
Millville	C., H. V. & T. R. R	752.
Monday Creek Station	C., H. V. & T. R. R	689.
Orbiston	C., H. V. & T. R. R	699.
Union Furnace	C., H. V. & T. R. R	748.
Starr	C., H. V. & T. R. R	775.
Winona Furnace	C., H. V. & T. R. R	743.
Holmes County.		
Black Creek	C., A. & C. R. R	868.
Lakeville	P., Ft. W. & C. R. R	954.
Millersburg	C., A. & C. R. R	816.
Millersburg, top of hills near	Ohio Geological Survey, Whittlesey	1235.
Summit, bet. Killbuck & Mohican	Ohio Geological Survey, Whittlesey	1160.
Huron County.		
Bellevue	L. S. & M. S. R. R	755.
Centerton	B. & O. R. R	873.
Chicago Junction	B. & O. R. R	901.
Collins	L. S. & M. S. R. R	879.
Greenwich	C., C., C. & I. R. R	1037.
Havana	B. & O. R. R	813.
Monroeville	L. S. & M. S. R. R	725.
New Haven	B. & O. R. R	918.
New London	C., C., C. & I. R. R	980.
Norwalk	L. S. & M. S. R. R	719.
Pontiac	B. & O. R. R	763.
Wakeman	L. S. & M. S. R. R	862.
Jackson County.		
Coalton	D. & I. R. R	718.
Jackson	Ohio Geological Survey, Whittlesey	795.
Raysville	C., W. & B. R. R	636.
Wellston	D. & I. R. R	738.
Jefferson County.		
Bloomfield	P., C. & St. L. R. R	905.
Bloomfield, top of hill 1 mile East of	Ohio Geological Survey—Newberry	1434.
Brown's	C. & P. R. R	683.
Elliottsville	C. & P. R. R	638.
Gould	P., C. & St. L. R. R	679.
Hammondsville	C. & P. R. R	688.
La Grange	C. & P. R. R	679.
Linton	C. & P. R. R	694.
McCoy's Station	C. & P. R. R	684.
Mingo	P., C. & St. L. R. R	667.
Mingo	C. & P. R. R	687.
Portland Station	C. & P. R. R	679.
Reed's Mills	P., C. & St. L. R. R	811.
Rush Run	C. & P. R. R	679.
Skelley's Station	P., C. & St. L. R. R	841.
Sloan's Station	C. & P. R. R	698.
Smithfield Station	P., C. & St. L. R. R	773.
Steubenville	C. & P. R. R	679.
Steubenville	P., C. & St. L. R. R	728.

Station.	Authority.	Elevation.
Jefferson County—Concluded.		
Toronto	C. & P. R. R	698.
Unionport	P., C. & St. L. R. R	946.
Yorkville	C. & P. R. R	671.
Knox County.		
Bangs	C., A. & C. R. R	1102.
Centerburg, crossing C., A. & C. R R	T. & O. C. R. R	1190.
Centerburg, crossing T. & O. C. R. R	C., A. & C. R. R	1209.
Danville	C., A. & C. R. R	968.
Gambier	C., A. & C. R. R	965.
Gann	C., A. & C. R. R	874.
Howard	C., A. & C. R. R	900.
Mt. Liberty	C., A. & C. R. R	1215.
Mt. Vernon	B. & O. R. R	991.
Lake County.		
Grand River	L. S. & M. S. R R	660.
Litttle Mountain, Geodetic Station	U. S. Lake Survey	1248.
Madison	L. S. & M. S. R. R	715.
Mentor	L. S. & M. S. R. R	650.
Painesville	L. S. & M. S. R. R	650.
Perry	L. S. & M. S. R. R	707.
Unionville	L. S. & M. S. R. R	704.
Wickliffe	L. S. & M. S. R R	607.
Willoughby	L. S. & M. S. R. R	635.
Willoughby, Geodetic Station	U. S. Lake Survey	613.
Lawrence County.		
Hanging Rock	S. V. R. R	557.
Ironton, Center street crossing	S. V. R. R	550.
Petersburg (Coal Grove)	S. V. R. R	558.
Licking County.		
Alexander	T. & O. C. R. R	950.
Croton	T. & O. C. R. R	1160.
Granville	T. & O. C. R R	906.
Hanover	P., C. & St. L. R. R	830.
Hebron	T. & O. C. R. R	885.
Jacktown	Ohio Geological Survey, Whittlesey	1075.
Jacktown, summit of hill near	Ohio Geological Survey, Whittlesey	1235.
Johnstown	T. & O. C. R. R	.....
Licking Summit Ohio Canal	P., C. & St. L. R. R	892.
Montgomery	P., C. & St. L. R. R	800.
Newark	P., C. & St. L. R. R	819.
Newark, north end of city	B. & O. R. R	791.
P., C. & St. L. crossing	T. & O. C. R. R	880.
Logan County.		
Bellefontaine	I., B. & W. R. R	1216.
Bellefontaine, summit 4 miles east of	C., C., C. & I. R. R	1346.
Bellefontaine, summit 1½ mile east of	Ohio Geological Survey—Hill	1540.
DeGraff	C., C., C. & I. R. R	989.
East Liberty	Ohio Geological Survey—Winchell	1138.
Gretna	C., C., C. & I. R. R	1086.
Harper	C., C., C. & I. R. R	1299.
Middleburg	Ohio Geological Survey—Winchell	1198.

Station.	Authority.	Elevation.
Logan County—Concluded.		
Quincy	C., C., C. & I. R. R.	1050.
Rushsylvania	C., C., C. & I. R. R.	1236.
West Liberty	I., B. & W. R. R.	1099.
Top of hill 2 miles west of East Liberty	Ohio Geological Survey—Winchell.	1378.
Lorain County.		
Amherst	L. S. & M. S. R. R.	695.
Belden	C., L. & W. R. R.	860.
Black River	C., L. & W. R. R.	611.
Brownhelm	L. S. & M. S. R. R.	640.
Columbia	C., C., C. & I. R. R.	802.
Elyria	L. S. & M. S. R. R.	713.
Elyria, Geodetic Station	U. S. Lake Survey	755.
Grafton	C., C., C. & I. R. R.	801.
Grafton, Geodetic Station	U. S. Lake Survey	954.
Hart's	C., L. & W. R. R.	693.
Kipton	L. S. & M. S. R. R.	853.
La Grange	C., C., C. & I. R. R.	828.
North Eaton	C., C., C. & I. R. R.	811.
Oberlin	L. S. & M. S. R. R.	815.
Patterson	C., L. & W. R. R.	771.
Ridgeville	L. S. & M. S. R. R.	686.
Rochester	C., C., C. & I. R. R.	935.
Shawville	L. S. & M. S. R. R.	744.
Wellington	C., C., C. & I. R. R.	859.
Lucas County.		
Air Line Junction	L. S. & M. S. R. R.	607.
Holland	L. S. & M. S. R. R.	641.
South Toledo	W., St. L. & P. R. R.	639.
Swanton	L. S. & M. S. R. R.	685.
Sylvania	L. S. & M. S. R. R.	652.
Toledo, Union depot	L. S. & M. S. R. R.	580.
Toledo	T. & O. C. R. R.	583.
Toledo	W., St. L. & P. R. R.	583.
Toledo	D. & M. R. R.	585.
Toledo	C., H. V. & T. R. R.	586.
Toledo	L. S. & M. S. R. R.	586.
Toledo, Air Line Junction	L. S. & M. S. R. R.	611.
Toledo, Lock 1	Miami & Erie Canal	579.9
Toledo, Lock 2	Miami & Erie Canal	587.9
Toledo, Lock 3	Miami & Erie Canal	595.4
Toledo, Lock 4	Miami & Erie Canal	604.4
Toledo, Lock 5	Miami & Erie Canal	612.4
Toledo, low water in Maumee river	W. & L. E. R. R.	573.
Toledo, Signal Office	U. S. Signal Office	651.
White House	W., St. L. & P. R. R.	653.
Madison County.		
County Infirmary	Ohio Geological Survey—Orton	1100.
Duff's Fork	C. & C. M. R. R.	895.
London	P., C. & St. L. R. R.	1049.
Midway	Ohio Geological Survey—Orton	950.
Mount Sterling	C. & C. M. R. R.	915.
West Jefferson	P., C. & St. L. R. R.	908.

Station.	Authority.	Elevation.
Mahoning County.		
Austintown	N. Y., P. & O. R. R.	1012.
Brier Hill	N. Y., P. & O. R. R.	880.
Canfield	N. Y., P. & O. R. R	1160.
Damascus	P., Ft. W. & C. R. R.	1188.
Lowell	L. S. & M. S. R. R.	826.
Nebo	A. & P. R. R.	840.
Thorn Hill	N. Y., P. & O. R. R.	869.
Washingtonville	N. Y., P. & O. R. R.	1059.
Youngstown	N. Y., P. & O. R. R.	863.
Marion County.		
Acton Summit	C., H. V. & T. R. R.	944.
Berwick	N. Y., P. & O. R. R.	918.
Caledonia	C., C., C. & I. R. R.	996.
Caledonia	N. Y., P. & O. R. R.	1066.
Clifton's	C. & A. R. R.	982.
Green Camp, water tank	N. Y., P. & O. R. R.	920.
La Rue	C., C., C. & I. R. R.	926.
Little Scioto River	C., H. V. & T. R. R.	920.
Locust Switch	N. Y., P. & O. R. R.	1053.
Marion	C., C., C. & I. R. R.	979.
Marion, C., C., C. & I. crossing	N. Y., P. & O. R. R.	965.
Marion	C. & A. R. R.	975.
Marion	C., H. V. & T. R. R.	951.
Martel, N. Y., P. & O. crossing	T. & O. C. R. R.	1037.
Morral	C., H. V. & T. R. R.	908.
Owen's	C., H. V. & T. R. R.	957.
Prospect	C., H. V. & T. R. R.	918.
Summit	C., H. V. & T. R. R.	983.
Medina County.		
Chippewa	C., L. & W. R. R.	1056.
Lodi	W. & L. E. R. R.	855.
Medina	C., L. & W. R. R.	1086.
Seville	C., L. & W. R. R.	986.
Styx River, surface of water	N. Y., P. & O. R. R.	1169.
Wadsworth	N. Y., P. & O. R. R.	1349.
Meigs County.		
Carpenter's	T. & O. C. R. R.	621.
Dexter	T. & O. C. R. R.	599.
Dyesville	T. & O. C. R. R	602.
Langsville	T. & O. C. R. R.	572.
Middleport	T. & O. C. R. R	563.
Middleport	C., H. V. & T. R. R.	564.
Pomeroy	C., H. V. & T. R. R.	565.
Pomeroy, low water in Ohio River	C., H. V. & T. R. R.	517.
Pomeroy, high water, flood of 1884	C., H. V. & T. R. R.	578.
Mercer County.		
Celina, grade of L. E. & W. at station	Ohio Geological Survey—Orton—(Barometer)	873.
St. John's	Ohio Geological Survey—Winchell	1003.
St. John's	Ohio Geological Survey—Winchell	1064.
St. Mary's, Canal level	Ohio Geological Survey, Whittlesey	851.

Station.	Authority.	Elevation.
Miami County.		
Covington	C., St. L. & P. R. R	923.
Bradford	C., St. L. & P. R. R	005.
Kessler	I., B. & W. R. R	925.
Laura	I., B. & W. R. R	970.
Ludlow Falls	I., B. & W. R. R	900.
Miami City	P., C. & St. L. R. R	744.
Piqua	C., St. L. & P. R. R	884.
Piqua	D. & M. R. R	918.
Tippecanoe City	D. & M. R. R	843.
Troy	D. & M. R. R	850.
Troy, D. & M. crossing	I., B. & W. R. R	847.
Troy, Canal	Miami & Erie Canal	830.
Monroe County.		
Beallsville	B., Z. & C. R. R	1270.
Jerusalem	B., Z. & C. R. R	1300.
Ozark	B., Z. & C. R. R	1265.
Woodsfield	B., Z. & C. R. R	1173.
Montgomery County.		
Alexandersville	C., C., C. & I. R. R	725.
Brookville	P., C. & St L. R. R	1033.
Dayton, D. & M. crossing	Miami Canal	739.
Dayton	Union Depot	743.
Dayton, Third street	C., H. & D. R. R	756.
Dodson	P., C. & St. L. R. R	1051.
Harshmanville	C., C., C. & I. R. R	783.
Miamisburg	C., C., C. & I R. R	714.
Miamisburg	C, H. & D. R. R	649.
Stillwater Junction	P., C. & St. L. R. R	791.
Trotwood	P., C. & St. L. R. R	844.
Morgan County.		
McConnellsville, Ohio Meteorological Station	Ohio Meteorological Bureau	704.
Morrow County.		
Bloomfield Cemetery, N. W. ¼ sec. 17.	Ohio Geological Survey Winchell.	1149.
Cardington	C., C., C. & I. R. R.	1011.
Chesterville	Ohio Geological Survey—Winchell.	893.
Climax	T. & O. C. R. R	1032.
Edison, crossing Bee Line R. R.	T. & O. C. R. R	1056.
Fulton	T. & O. C. R. R	1106.
Marengo	T. & O. C. R. R	1119.
Mt. Gilead, crossing Short Line R. R.	T. & O. C. R R	1091.
Mt. Gilead, Edison Station	C., C., C. & I. R. R	1039.
Iberia	C., C., C. & I. R. R	1156.
Muskingum County.		
Adams' Mills	P., C. & St. L. R. R	731.
Adams' Mills, Lock 27	Ohio Canal	744.52
Adams' Mills, Lock 28	Ohio Canal	734.52
Adams' Mills, Lock 29	Ohio Canal	724.52
Bridgewater	C. O. (B. & O.) R. R	869.
Concord	C. O. (B. & O.) R. R	845.
Dresden	P., C. & St. L. R. R	735.

Station.	Authority.	Elevation.
Muskingum County—Concluded.		
Dresden Junction	C. & M. V. R. R.	768.
Ellis	C. & M. V. R. R.	779.
Frayzeysburg	P., C. & St. L. R. R.	751.
Nashport Road	P., C. & St. L. R. R.	773.
Norwich	C. O. (B. & O.) R. R.	884.
Norwich, Summit	C. O. (B. & O.) R. R.	954.
Putnam	Ohio Geological Survey, Whittlesey	723.
Roseville	C. & M. V. R. R.	783.
Zanesville	C. & M. V. R. R.	700.
Zanesville, top of dam Muskingum River	Ohio Geological Survey, Whittlesey	686
Noble County.		
Ava	C. & M. R. R.	774.
Belle Valley	C. & M. R. R.	743.
Caldwell	C. & M. R. R.	743.
Caldwell	B., Z. & C. R. R.	845.
Dexter City	C. & M. R. R.	682.
Dudley	C. & M. R. R.	705.
Hiramsburg	C. & M. R. R.	760.
South Olive	C. & M. R. R.	689.
Tunnel	C. & M. R. R.	868.
Ottawa County.		
Danbury, Geodetic Station	U. S. Lake Survey	594.
Elmore	L. S. & M. S. R. R.	658.
Genoa	L. S. & M. S. R. R.	629.
Graytown	L. S. & M. S. R. R.	601.
Martin	L. S. & M. S. R. R.	606.
Oak Harbor	L. S. & M. S. R. R.	596.
Port Clinton	L. S. & M. S. R. R.	581.
Paulding County.		
Antwerp	W., St. L. & P. R. R.	729.
Cecil	W., St. L. & P. R. R.	723.
Indiana State Line	W., St. L. & P. R. R.	745.
Perry County.		
Corning	T. & O. C. R. R.	722.
McLuney	C. & M. V. R. R.	905.
Moxahala	T. & O. C. R. R.	821.
New Lexington	T. & O. C. R. R.	856.
New Lexington	C. & M. V. R. R.	897.
New Straitsville	C., H. V. & T. R. R.	792.
Rendville	T. & O. C. R. R.	742.
Somerset	Ohio Geological Survey, Whittlesey	1159.
Summit LaRue's Gap, Shawnee	Ohio Geological Survey, Whittlesey	909.
Pickaway County.		
Ashville	S. V. R. R.	716.
Circleville	C. & M. V. R. R.	720.
Darby Creek	C. & C. M. R. R.	763.
Deer Creek	C. & C. M. R. R.	858.
Derby	C. & C. M. R. R.	923.
Duvall	S. V. R. R.	714.
Elmwood	S. V. R. R.	741.

Station.	Authori y.	Elevation.
PICKAWAY COUNTY—Concluded.		
Hayesville	S. V. R. R	716.
New Holland	C. & M. V. R. R	876.
Palestine	C. & C. M. R. R.	884.
Williamsport	C. & M. V. R. R.	783.
PIKE COUNTY.		
Big Run	S. V. R. R	555.
Byington (railroad grade)	Ohio Geological Survey—Orton	672.
Fort Hill	Ohio Geological Survey—Orton	1285.
Jasper, Scioto bottoms	Ohio Geological Survey—Orton	566.
Jasper Knob	Ohio Geological Survey—Orton	1194.
Latham	Ohio Geological Survey—Orton	631.
Latham, hill South-east of	Ohio Geological Survey—Orton	1224.
Painter's Knob	Ohio Geological Survey—Orton	1196.
Piketon	S. V. R. R	570.
Riley's Mountain	Ohio Geological Survey—Orton (by barometer)	1150.
Sargent's	S. V. R. R	577.
Sharonville	S. V. R. R	597.
Shephard's Mountain	Ohio Geological Survey—Orton (by barometer)	1170.
Waverly, depot	S. V. R. R.	574.
Wetmore	S. V. R. R.	558.
PORTAGE COUNTY.		
Atwater	C. & P. R. R	1133.
Atwater Center	Ohio Geological Survey—Newberry	1173.
Atwater summit	C. & P. R. R	1176.
Aurora	N. Y., P. & O. R. R	1104.
Campbellsport	Ohio Geological Survey—Newberry	983.
Charlestown Center	Ohio Geological Survey—Newberry	1148.
Drakesburg	Ohio Geological Survey—Newberry	1208.
Earlville	C. & P. R. R	1091.
Edinburg	Ohio Geological Survey—Newberry	1183.
Freedom	N. Y., P. & O. R. R	1150.
Freedom, summit near	N. Y., P. & O. R. R	1186.
Garrettsville	N. Y., P. & O. R. R	1019.
Hiram, summit near	Colton	1336.
Kent	N. Y., P. & O. R. R	1050.
Limestone Ridge	Ohio Geological Survey—Newberry	1248.
Mantua	N. Y., P. & O. R. R	1111.
Ravenna	N. Y., P. & O. R. R	1093.
Ravenna Station	C. & P. R. R	1103.
Ravenna Public Square	C. & P. R. R	1133.
Rootstown	C. & P. R. R	1123.
Windham	N. Y., P. & O. R. R	964.
PREBLE COUNTY.		
Brinley's	P., C. & St. L. R. R	1124.
Camden, general level of town	Ohio Gelogical Survey—Orton	839.
Eaton, sill of old Court House	Ohio Geological Survey—Whittlesey	1044.
El Dorado	P., C. & St. L. R. R.	1178.
Florence	C., R. & C. R. R.	1140.
Lewisburg	Ohio Geological Survey—Orton	927.
New Paris	P., C. & St. L. R. R	1020.
Sonora	P., C & St. L. R. R	1039.
West A exandria	Ohio Geological Survey—Orton (by barometer)	859.
Winchester	Ohio Geological Survey—Orton (by barometer)	857.

Station.	Authority.	Elevation.
Putnam County.		
Belmore	D. & M. R. R.	732.
Columbus Grove	D. & M. R. R.	752.
Leipsic	D. & M. R. R.	746.
Ottawa	D. & M. R. R.	713.
Richland County.		
Lucas	P., Ft. W. & C. R. R.	1091.
Mansfield	P., Ft. W. & C. R. R.	1151.
Mansfield	B. & O. R. R.	1154.
Mansfield, P., Ft. W. & C. crossing	N. Y., P. & O. R. R.	1155.
Ontario	N. Y., P. & O. R. R.	1377.
Plymouth	B. & O. R. R.	993.
Richland	P., Ft. W. & C. R.	1201.
Richland crossing	P., Ft. W. & C. R. R.	1213.
Shelby	B. & O. R. R.	1088.
Shelby Junction	B. & O. R. R.	1086.
Shelby	C., C., C. & I. R. R.	1117.
Shiloh	C., C., C. & I. R. R.	1080.
Spring Mills	B. & O. R. R.	1176.
Spring Mills crossin	P., Ft. W. & C. R. R.	1212.
Vernon Junction	C., C., C. & I. R. R.	1127.
Summit, South-east part of county	Ohio Geological Survey—Whittlesey	1400.
Highest hills of Richland county	Ohio Geological Survey—Newberry	1475.
Ross County.		
Anderson	C., W. & B. R. R.	708.
Buckskin	C., W. & B. R. R.	926.
Chillicothe	C., W. & B. R. R.	635.
Chillicothe	D. & I. R. R.	638.
Frankfort	D. & I. R. R.	750.
Higby	S. V. R. R.	594.
Hopetown	S. V. R. R.	675.
Kingston	S. V. R. R.	770.
Kinnikinnick	S. V. R. R.	672.
Londonderry	C., W. & B. R. R.	625.
Londonderry	U. S. Coast and Geodetic Survey	615.225
Lyndon	U. S. Coast and Geodetic Survey	912.228
Musselman Junction, East of	U. S. Coast and Geodetic Survey	700.219
Musselman Junction, West of	U. S. Coast and Geodetic Survey	712.757
Salt Creek	C., W. & B. R. R.	615.
Salt Creek	D. & I. R. R.	588.
Schooley's	C., W. & B. R. R.	666.
Schooley's, 1½ m. East of Station on C., W. & B. R. R.	U. S. Coast and Geodetic Survey	658.157
Scioto bridge	C., W. & B. R. R.	625.
Three Locks	S. V. R. R.	617.
Walnut Creek, 1½ mile East of Schooley's	U. S. Coast and Geodetic Survey	658.157
Sandusky County.		
Clyde	L. S. & M. S. R. R.	691.
Fremont	L. S. & M. S. R. R.	632.
Lindsey	L. S. & M. S. R. R.	622.

Station.	Authority.	Elevation.
Scioto County.		
Davis's	S. V. R. R	567.
Dry Run	C., W. & B. R. R	657.
Franklin Furnace (Ohio river)		549.
Haverhill	S. V. R. R	553.
Johnson's	S. V. R. R	554.
Lucasville	S. V. R. R	556.
Portsmouth, S. V. Depot	S. V. R. R	533.
Portsmouth, low water in Ohio river.	Ohio Geological Survey	477.
Portsmouth, C., W. & B. Junction	S. V. R. R	538.
Sciotoville, C., W. & B. Junction	S. V. R. R	546.
Wheelersburg	S. V. R. R	540.
Seneca County.		
Alvada, summit	C., H. V. & T. R. R	851.
Attica	B. & O. R. R	964.
Bascom	B. & O. R. R	783.
Berwick	T. & O. C. R. R	840.
Fostoria, B. & O. crossing	T. & O. C. R. R	777.
Fostoria	L. E. & W. R. R	782.
Fostoria, B. & O. crossing	C., H. V. & T. R. R	773.
Kansas	L. E. & W. R. R	731.
McCutchenville	T. & O. C. R. R	800.
New Reigel	T. & O. C. R. R	822.
Republic	B. & O. R. R	885.
Tiffin	B. & O. R. R	759.
West Prairie	C., H. V. & T. R. R	807.
Shelby County.		
Anna	D. & M. R. R	1018.
Botkins	D. & M. R. R	954.
Houston	C., C., C. & I. R. R	959.
Pemberton	C., C., C. & I. R. R	1063.
Russia	C., C., C. & I. R. R	971.
Sidney	C., C., C. & I. R. R	969.
Sidney	D. & M. R. R	1001.
Sidney	Miami & Erie Canal	949.
Spafford	C., C., C. & I. R. R	1033.
Summit	D. & M. R. R. R	1053.
Stark County.		
Alliance	P., Ft. W. & C. R. R	1083.
Alliance	C. & P. R. R	1089.
Alliance, summit South of	Ohio Geological Survey, Whittlesey	1202.
Barr's Mills	C. & W. R. R	965.
Beach City, summit	C. & C. R. R	1058.
Canal Fulton	C., L. & W. R. R	947.
Canton	V. R. R	1039.
Canton	P., Ft. W. & C. R. R	1047.
Greentown	V. R. R	1103.
Justus	C., L. & W. R. R	994.
Limaville	C. & P. R. R	1098.
Louisville	P., Ft. W. & C. R. R	1117.
Massillon	P., Ft. W. & C. R. R	954.
Massillon	C., L. & W. R. R	963.
Massillon	W. & L. E. R. R	962.
Massillon, Lock 5	Ohio Canal	939.5
Massillon, Mines	P., Ft. W. & C. R. R	958.

Station.	Authority.	Elevation.
Stark County—Concluded.		
Minerva	C. & P. R. R	1052.
Navarre	C., L. & W. R. R	993.
Navarre, Lock 6	Ohio Canal	923.5
Nimishillen	P., Ft. W. & C. R. R	1147.
Strasburg	P., Ft. W. & C. R. R	1187.
Strasburg	P., Ft. W. & C. R. R	1089.
Osnaburg, summit cut	C. & C. R. R	1177.
Uniontown	V. R. R	1073.
Waynesburg	C. & P. R. R	981.
Wilmot, top of hill	Ohio Geological Survey, Whittlesey	1261.
Summit County.		
Akron, East	V. R. R	975.
Akron, summit near	Ohio Geological Survey, Whittlesey	1175.
Akron, summit West of	Ohio Geological Survey, Whittlesey	1081.
Akron	N. Y., P. & O. R. R	1003.
Akron, Ohio Canal, summit level, high water	Ohio Geological Survey, Newberry	968.
Boston	V. R. R	653.
Botzum's	V. R. R	748.
Clinton	C., A. & C. R. R	959.
Cuyahoga Falls	C., A. & C. R. R	1011.
Cuyahoga Falls River, rail	P., C. & T. R. R	1047.
Dennison	N. Y., P. & O. R. R	1308.
Everett	V. R. R	725.
Hudson Station	C. & P. R. R	1053.
Hudson Village	C. & P. R. R	1120.
Krumroy	V. R. R	1049.
Macedonia	C. & P. R. R	993.
New Portage	N. Y., P. & O. R. R	1204.
Northfield Summit	C. & P. R. R	1043.
Peninsula	V. R. R	699.
Peninsula Lock	Ohio Canal	702.5
Silver Creek	N. Y., P. & O. R. R	1392.
Tallmadge	N. Y., P. & O. R. R	1333.
Trumbull County.		
Bloomfield	A. & P. R. R	905.
Braceville	N. Y., P. & O. R. R	907.
Burg Hill	N. Y., P. & O. R. R	1044.
Church Hill	N. Y., P. & O. R. R	1017.
Courtland	N. Y., P. & O. R. R	999.
Girard	N. Y., P. & O. R. R	865.
Hubbard	N. Y., P. & O. R. R	937.
Johnston Summit	N. Y., P. & O. R. R	1126.
Leavittsburg	N. Y., P. & O. R. R	907.
Liberty, water tank	N. Y., P. & O. R. R	1071.
Mahoning Summit Swamp	Ohio Geological Survey--Whittlesey	915.
Mesopotamia, Geodetic Station	U. S. Lake Survey	1172.
Mineral Ridge	N. Y., P. & O. R. R	970.
Niles	N. Y., P. & O. R. R	889.
Orangeville	N. Y., P. & O. R. R	945.
Phalanx (Braceville)	N. Y., P. & O. R. R	918.
State Line	N. Y., P. & O. R. R	852.
Vienna Junction	N. Y., P. & O. R. R	869.
Warren	N. Y., P. & O. R. R	900.
Warren Station	N. Y., P. & O. R. R	883.

Station.	Authority.	Elevation.
Tuscarawas County.		
Black Band	C. & M. R. R	903.
Bolivar, Lock 8	Ohio Canal	906.52
Canal Dover	C. & P. R. R	884.
Canal Dover, Lock 12	Ohio Canal	878.52
Dennison	P., C. & St. L. R. R	855.
Gnadenhutten	Ohio Canal	829.52
Goshen	C., L. & W. R. R	853.
Mineral Point	C. & P. R. R	959.
Mt. Tabor	Ohio Geological Survey—Newberry	1348.
New Castle, Canal	Ohio Geological Survey—Newberry	852.
Newcomerstown	P., C. & St. L. R. R	796.
Newcomerstown, Lock 21	Ohio Canal	800.5
New Philadelphia	C., L. & W. R. R	874.
New Philadelphia	C. & P. R. R	904.
Newport	C., L. & W. R. R	870.
Phillipsburg	C. & M. R. R	930.
Port Washington	P., C. & St. L. R. R	813.
Port Washington, Lock	Ohio Canal	823.5
Port Washington, hill tops north of	Ohio Geological Survey—Newberry	1298.
Post Boy	C. & M. R. R	828.
Stillwater	C., L. & W. R. R	863.
Strasburg	C., L. & W. R. R	917.
Trenton	P., C. & St. L. R. R	833.
Trenton, Lock 15	Ohio Canal	848.5
Trenton, Lock 16	Ohio Canal	840.5
Tuscarawas	C., L. & W. R. R	827.
Uhrichsville	P., C. & St. L. R. R	863.
Uhrichsville, top of hills	Ohio Geological Survey—Newberry	1153.
Wolf's Station	C. & M. R. R	837.
Zoar Station	C. & P. R. R	887.
Zoar Mills, Lock	Ohio Canal	892.5
Zoar, top of hills	Ohio Geological Survey—Newberry	1173.
Union County.		
Allen Center	Ohio Geological Survey—Winchell (by barometer)	1008.
Broadway	N. Y., P. & O. R. R	1032.
Dover	C., C., C. & I. R. R	971.
Essex	Ohio Geological Survey—Winchell (by barometer)	932.
Irwin	C., C., C. & I. R. R	1012.
Marysville	C., C., C. & I. R. R	999.
Mifford Center	C., C., C. & I. R. R	996.
New California	Ohio Geological Survey—Winchell (by barometer)	948.
Newton	Ohio Geological Survey—Winchell (by barometer)	1033.
Peoria	N. Y., P. & O. R. R	1044.
Pottersburg	N. Y., P. & O. R. R	1093.
Richwood	N. Y., P. & O. R. R	948.
Woodland	N. Y., P. & O. R. R	950.
York Center	Ohio Geological Survey—Winchell (by barometer)	972.
Pharisburg	Ohio Geological Survey—Winchell (by barometer)	877.
Plain City	Ohio Geological Survey—Winchell (by barometer)	798.

Station.	Authority.	Elevation.
VAN WERT COUNTY.		
Conway	P., Ft. W. & C. R. R.	791.
Delphos	P., Ft. W. & C. R. R	784.
Delphos, Lock	Miami & Erie Canal	784.
Enterprise	C. & A. R. R.	847.
Dixon	P., Ft. W. & C. R. R.	798.
Middleport	P., Ft. W. & C. R. R.	784.
Rivare	C. & A. R. R	851.
Van Wert	P., Ft. W. & C. R. R.	784.
VINTON COUNTY.		
Baird's Summit	C., H. V. & T. R. R	796.
Big Sand Furnace	C., W. & B. R. R.	712.
Creola	C., H. V. & T. R. R.	729.
Eagle Furnace	C., H. V. & T. R. R.	691.
Hamden	U. S. Coast and Geodetic Survey	706.778
Hamden	C., W. & B. R. R.	721.
Hawks	C., H. V. & T. R. R.	639.
McArthur	C., H. V. & T. R. R.	730.
Minerton	C., H. V. & T. R. R	627.
Moonville	C., W. & B. R. R	723.
New Plymouth	C., H. V. & T. R. R.	776.
Radcliff	C., H. V. & T. R. R.	645.
Swan	C., H. V. & T. R. R.	760.
Vinton Furnace Station	C., W. & B. R. R	711.
Zaleski	C., W. & B. R. R.	721.
Zaleski, 1 m. South of	U. S. Coast and Geodetic Survey	714.884
WARREN COUNTY.		
Avoca	C. N. R. R.	689.
Corwin	P., C. & St. L. R. R	729.
Fort Ancient	P., C. & St. L. R. R.	669.
Foster's	P., C. & St. L. R. R.	600.
Franklin	C., C., C. & I. R. R	693.
Lebanon	C. N. R. R.	709.
Mason	C. N. R. R.	827.
Morrow	C. & M. V. R. R	666.
Pleasant Plain	C., W. & B. R. R.	902.
Shakers'	C. N. R. R.	745.
South Lebanon	P., C. & St. L. R. R.	628.
WASHINGTON COUNTY.		
Belpre	C., W. & B. R. R.	630.
Caywood	C. & M. R. R	614.
Cutler	C., W. & B. R. R	777.
Elba	C. & M. R. R	664.
Harmar	C., W. & B. R. R.	623.
Little Hocking	U. S. Coast and Geodetic Survey	623.969
Macksburg	C. & M. R. R.	680.
Marietta, Fourth street depot	C., W. & B. R. R.	616.
Marietta, Muskingum river crossing	C., W. & B. R. R	640.
Marietta, low water in Muskingum river	C., W. & B. R. R.	582.
Salem Station	C. & M. R. R.	682.
Stanley	C. & M. R. R	629.
Vincent's	Marietta Mineral R'y	774.
Warner	C. & M. R. R	675.
Whipple	C. & M. R. R	656.

Station.	Authority.	Elevation.
Wayne County.		
Apple Creek	C., A. & C. R. R.	942.
Burbank	N. Y., P. & O. R. R.	958.
Easton	C., L. & W. R. R.	961.
Fairview	P., Ft. W. & C. R. R.	1024.
Fredericksburg	C., A. & C. R. R.	968.
Jackson	W. & L. E. R. R.	761.
Milton	N. Y., P. & O. R. R.	1193.
Orrville	C., A. & C. R. R.	1056.
Orrville, C., A. & C. crossing	P., Ft. W. & C. R. R.	1058.
Orrville,	P., Ft. W. & C. R. R.	1072.
Pike Station	N. Y., P. & O. R. R.	982.
Russell, C., L. & W. crossing	N. Y., P. & O. R. R.	973.
Shreve	P., Ft. W. & C. R. R.	925.
Smithville	P., Ft. W. & C. R. R.	1122.
Warwick	C., L. & W. R. R.	958.
West Salem	N. Y., P. & O. R. R.	1095.
Windsor	N. Y., P. & O. R. R.	1067.
Wooster	P., Ft. W. & C. R. R.	915.
Wooster, summit	P., Ft. W. & C. R. R.	1136.
Summit, Northwest part of county	Ohio Geological Survey, Whittlesey	1275.
Williams County.		
Bear Creek	L. S. & M. S. R. R.	698.
Bryan	L. S. & M. S. R. R.	765.
Edgerton	L. S. & M. S. R. R.	830.
Melbern	L. S. & M. S. R. R.	843.
Melbern, summit West of	L. S. & M. S. R. R.	877.
Stryker	L. S. & M. S. R. R.	715.
Wood County.		
Bairdstown	B. & O. R. R.	747.
Bloomdale	B. & O. R. R.	756.
Bowling Green	T. & S. R. R.	703.
Bradner	C., H. V. & T. R. R.	693.
Dunbridge	T. & S. R. R.	668.
Hatton	T. & O. C. R. R.	704.
Hoyt's Corners	B. & O. R. R.	721.
Le Moyne	C., H. V. & T. R. R.	638.
Lime City	T. & S. R. R.	650.
Luckey	T. & O. C. R. R.	673.
Millbury Junction	L. S. & M. S. R. R.	615.
Milton Center	D. & M. R. R.	690.
Montgomery	D. & M. R. R.	667.
North Baltimore	B. & O. R. R.	740.
Pemberville	C., H. V. & T. R. R.	648.
Pemberville	T. & O. C. R. R.	657.
Perrysburg	D. & M. R. R.	622.
Portage	T. & S. R. R.	686.
Prairie Depot	T. & O. C. R. R.	698.
Rising Sun	C., H. V. & T. R. R.	707.
Stony Ridge	T. & O. C. R. R.	644.
Tontogany	D. & M. R. R.	652.
Trombly	T. & S. R. R.	701.
Walbridge	C., H. V. & T. R. R.	620.
Welker	T. & S. R. R.	736.

Station.	Authority.	Elevation.
	WYANDOT COUNTY.	
Carey	I., B. & W. R. R.	
Carey	C. H. V. & T. R. R.	813.
Cranberry Marsh	I., B. & W. R. R	929
Deunquat	T. & O. C. R. R.	906.
Edenville	P., Ft. W. & C. R. R.	928.
Fowler	C., H. V. & T. R. R.	899.
Kirby	P., Ft. W. & C. R. R.	882.
Nevada	P., Ft. W. & C. R. R	932.
Sycamore	T. & O. C. R. R.	853.
Upper Sandusky	P., Ft. W. & C. R. R.	860.
Upper Sandusky, P., Ft. W. & C. crossing	C., H. V. & T. R. R.	848.

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